U. S. Grant Jr.
December 1927.

# TWENTIETH CENTURY TEXT-BOOKS

EDITED BY

A. F. NIGHTINGALE, PH. D., LL.D.

FORMERLY SUPERINTENDENT OF HIGH SCHOOLS, CHICAGO

The Viesch Glacier, Switzerland.

TWENTIETH CENTURY TEXT-BOOKS

# A TEXT-BOOK OF GEOLOGY

BY

ALBERT PERRY BRIGHAM, A. M., F. G. S. A.

PROFESSOR OF GEOLOGY IN COLGATE UNIVERSITY



NEW YORK
D. APPLETON AND COMPANY
1903

# PREFACE

In preparing this volume for secondary schools the author has made an elementary treatise, and has avoided technical discussions and terms so far as seemed consistent with the purposes of definite instruction. This is especially true in Part III, whose object is not the identification of horizons or species, but to give a general understanding of the progress of life and of the growth of the lands. But it has not been thought necessary to *write condescendingly* or in a juvenile style for students of high-school age. The great unsolved problems of the science of geology have been frankly stated, and interested students will, it is hoped, find glimpses of the vast regions that lie beyond the field of a brief exposition. Students will find it useful to have done some work in zoölogy and botany. For those who have not this preparation for Part III, the competent teacher may give the supplementary explanations that are needed. The order of treatment is deliberately chosen, and will not be found to differ in essentials from that employed in several earlier text-books. The phenomena of weathering and the various activities of water fall at once under the eye of most students. In the author's experience it has been found best to use at the outset the familiar interest thus aroused, thus leading on to more remote themes. Other text-books have been freely consulted, and record is here made of more especial indebtedness to Dana, Geikie, and Scott.

Occasional references to other works have been included in the text, but students desiring a fuller bibliography will find it in the teacher's pamphlet which accompanies the volume.

I desire to record special obligation to Dr. Charles E. Boynton and Mr. Robert E. Cutler, of the Chicago High Schools. These gentlemen have read the manuscript of the book, and have given many valuable suggestions.

Grateful acknowledgment is made to those who have freely aided in securing suitable illustrations. It is hoped that nothing has been introduced which does not truly illustrate the statements of the text. The descriptive titles have in many cases been made somewhat full.

The following have given me cordial assistance: Prof. H. L. Fairchild, University of Rochester; Prof. George H. Barton, Massachusetts Institute of Technology; Prof. William Libbey, Princeton University; Prof. W. H. C. Pynchon, Trinity College; Prof. Samuel Calvin, Iowa State University; Dr. F. J. H. Merrill, New York State Museum; Mr. N. H. Darton, United States Geological Survey; Dr. J. M. Clarke, State Paleontologist of New York, who has reviewed the selection of Paleozoic illustrations; Prof. W. M. Davis, Harvard University. Mr. S. R. Stoddard, Mr. W. G. C. Kimball, and Mr. C. H. James have kindly permitted the use of their views of the Adirondack region, the Bermuda Islands, and of Luray Cavern. Many cuts have been reproduced from Government and State Reports, and from photographs belonging to the Department of Geology in Colgate University. In Part III a considerable number have been taken, with the author's consent, from Le Conte's Elements of Geology.

In the teacher's guide, which accompanies this volume, I have inserted outlines of geological field excursions for eighteen of the greater American cities. It is hoped that these may be useful to teachers in the cities concerned, and may serve as a model to others. Outlines for several large centers were sought but not secured, hence the list has some serious gaps, such as St. Louis, New Orleans, Denver, and San Francisco. Should the scheme be of use, this defect may be remedied in future. I am under great obligation to those named below for the preparation of the several itineraries :

Mr. J. B. Woodworth, Harvard University (outline for Boston); Principal David W. Hoyt, English High School, Providence; Principal William Orr, Jr., High School, Springfield, Mass.; Prof. J. F. Kemp, Columbia University, New York; Prof. C. Stuart Gager, New York State Normal College, Albany (outline for Albany and Troy); Prof. I. P. Bishop, State Normal School, Buffalo; Miss Mary S. Holmes, Girls' High School, Philadelphia; J. Gordon Ogden, Ph. D., Fifth Avenue High School, Pittsburg; Mr. H. H. Hindshaw, Johns Hopkins University, Baltimore; Prof. H. P. Cushing, Western Reserve University, Cleveland; Principal George W. Harper, Woodward High School, Cincinnati; Prof. C. C. Lemon, Normal School, Detroit; Mr. D. C. Ridgley, West Division High School, Chicago; Prof. E. C. Case, Normal School, Milwaukee; Prof. C. W. Hall, University of Minnesota, Minneapolis and St. Paul; Mr. George H. Ashley, of the Indiana Geological Survey, Indianapolis; Major William J. Davis, Louisville. Professor Kemp was assisted in preparing the outline for New York by Messrs. Arthur Hollick and G. Van Ingen.

The author has sought to treat the several topics in proportion and without undue bias toward his own favorite studies, and hopes that no serious omissions will be found.

ALBERT PERRY BRIGHAM.

COLGATE UNIVERSITY, *October, 1900.*

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# GEOLOGY

## INTRODUCTION

**Geology and its departments.**—Geology deals with the history of the earth. It may have various subdivisions. For this text-book we treat the subject under the familiar heads of dynamical, structural, and historical geology.

Dynamical geology (*dynamis*, force or energy) treats of the forces that make changes upon or beneath the surface of the earth. Hence we speak of the work of the atmosphere, of water, heat, and life in the chapters that follow.

Structural geology explains the composition of rocks and the forms in which they occur. Thus some rocks are sandstones or limestones, others are slates or schists, and others are ancient or modern lavas. These occur in beds or masses of many kinds, and have often been folded, broken, or otherwise changed. As a result of composition, structure, and dynamic changes we have land forms, the study of which is included in Part II.

Historical geology takes the materials of force and structure and builds up a history of the globe, showing the succession of its rocks, the origin of its lands, and, in particular, tracing the progress of living creatures from remote ages until the present time.

**Geology and related sciences.**—Here the bond is close. Our science deals with the earth in its coming to be;

geography takes up the earth as it is, particularly in its relation to man: but no boundary can be drawn between the two subjects. Geology is dependent upon chemistry and physics, for all rocks have a chemical constitution and all dynamical operations are illustrations of physical laws. Astronomy aids us in understanding the earlier conditions of the globe. Zoölogy and botany contribute largely to historical geology, since only by their aid can we know the animals and plants of the ancient periods, and trace their evolution to the present time.

**The study of geology.**—Work in any branch of natural science should sharpen the observation, quicken the reasoning powers, and make us appreciative of the world about us. Geology offers its full measure of these advantages. Observation may deal with specimens in the school collection or laboratory, or with things seen in field excursions. Even the chance walks of the student will always put geological illustrations before him. The effort to construct conditions found in other lands and other ages will exercise the imagination. Particularly should the student of geology come the better to know the world in which he lives; to love its natural scenery because he understands it; to see meaning in its rocks and fossils and in the materials furnished by the earth's crust to the common arts of man. "Whatever frees one from the control of the senses, or tends to make the past, the distant, or the future predominate over the present, advances us in the dignity of thinking beings."

# PART I

# DYNAMICAL GEOLOGY

## CHAPTER I

### GEOLOGICAL WORK OF WINDS

1. **Force exerted.**—Winds are movements of the atmosphere. Since the atmosphere has weight, it applies energy, when in motion, to bodies which it meets. It thus becomes a geological agent, which is more important than is commonly supposed. Winds are effective according to their strength, their continuance, and the kind of materials which they find to work upon. The pressure exerted by winds of various velocities has been stated as follows:

| | Velocity in miles per hour. | Pressure in pounds per square foot. |
|---|---|---|
| Light breeze ........... ....... | 14 | 1 |
| Strong breeze .................... | 42 | 9 |
| Strong gale ...................... | 70 | 25 |
| Hurricane .... .................. | 84 | 36 |

2. **Kinds of work done.**—Winds attack materials on or near the earth's surface and accomplish erosion, transportation, and deposition.

The above terms are so important throughout the study of geology that their meaning should be at once understood.

*Erosion* is the most general term for the gradual destruction of earthy or rocky masses by any means, chemical or mechanical, as by solution, winds, rivers, or glaciers. The term *transportation* explains itself, but has special importance because of the incessant carriage of materials throughout all ages over all parts of the earth's surface. This will appear as we proceed. Such moving materials are ever coming to more or less enduring rest, in which they assume various topographic forms. To this phase of their history the term *deposition* is applied. Soon or late it follows all modes of transportation.

3. **Erosion by winds.**—Winds can not commonly lift or move rocky masses of any size by direct impact; but they can

Fig. 1.—Faceted pebble from Cape Cod, showing three faces made and polished by blown sand.

pick up sand grains in great numbers and hurl them against rock surfaces, producing a large amount of wear or abrasion.

Window glass is among the hardest of common substances, but its surface is readily ground by blowing sand and soon loses its transparency, as has been reported from exposed dwellings on Cape Cod. Pebbles and bowlders on the shores of Cape Cod and Martha's Vineyard and in the Androscoggin Valley have thus been scored by winds blowing in different directions, forming faces which meet in sharp angles. Hence they have been termed *faceted pebbles.*

This process is best seen upon dry plains and plateaus, as in some parts of the western United States, where winds are powerful and vegetation scant. Rock surfaces are polished or elaborately graven and etched, particularly if some layers of the rock are harder than others. As the sand moves chiefly near the ground, bowlders or pillars of rock may be thus undermined until they topple over, when the wear of the mass will be resumed at a new angle. Orange trees have thus been girdled in California, and the soft wood of telegraph poles cut away, leaving the knots standing in relief.

Such work in nature led to the use of a similar process in the arts, in which a current or jet of angular sand is driven against the surface which is to be abraded.

An interesting list of uses of the sand blast may be found in Appleton's Popular Science Monthly, September, 1895. Thus the process is employed for decorating glass, for cutting reliefs on stone, for bringing out the grain of wood, and for refacing grindstones and emery wheels.

The surface of the soil may be considerably disturbed by trees falling under the force of winds, especially in the track of a tornado. The hummocky surface of the forest grounds is often due to this cause. A disk of earth ten feet in diameter is not infrequently thus lifted. Upon the decay of the supporting roots the earth settles into a ridge with a pit beside it. Erosion may thus be favored by exposing soil to wind and water, or be retarded by obstruction of drainage. Such operations should not be thought trivial, for they are carried on over large areas and throughout long periods of time.

4. **Transportation by winds.**—The air always contains many particles of matter, which may be carried long distances by prevailing winds. This is especially true in times of drought, as may be seen along roadways and on plowed fields. Such transport is more important along the shores of the sea and of large lakes, where the sand often travels several miles inland and the finest dust much greater distances. But it is in dry regions that the process reaches its height and has great geological significance. Those who live in a moist region, whose soil is held down by a network of vegetation, can not well understand the severity of great sand storms in an arid country. Not seldom they overwhelm man and beast, hide the sun from view, and continue for many hours. Such a storm swept over some of the Northwestern States on May 6 and 7, 1899, and is thus described: "The air was filled with flying particles, caught up from the plowed fields, from the blackened prairies, from the public roads, and from all sandy plains. These particles formed dense clouds and rendered it as impossible to withstand the blast as it is to resist the 'blizzard' which carries snow in the winter over the same region. The soil, to the depth of four or five inches in some places, was torn up and scattered in all directions. Drifts of sand were formed in favorable places several feet high, packed precisely as snowdrifts are."

To this process is largely due the deep covering of soil and sand which hides the remains of many ancient cities in the East. Layard and others have encountered dust storms while engaged in uncovering such ruins. All work ceased, day was turned into night, and the laborers crouched in the trenches to save themselves from suffocation. Prof. J. A. Udden reports six sand storms as taking place in Arizona in 1893. Many more than this occur in parts of California.

The extent of single storms varies from 80 to 400 miles, and twenty-four hours is a safe average for their duration. The same writer estimates that hundreds or even thousands of tons of dust are carried in a cubic mile of air at such times.

Volcanoes are a great source of wind-borne dust. This will be explained in a later section. It is enough here to note that vast quantities of fine rocky matter are expelled in explosive eruptions and widely scattered over land and sea. The heavier particles descend in the vicinity, but the finer dust is carried to great heights in the air and distributed by the winds over the entire globe. Such dust was seen by many in Norway and Sweden on March 29 and 30, 1875. It fell on clothing, gave pain by lodging in the eyes, and was observed on the glass covering of greenhouses. It proceeded from an eruption in Iceland, several hundred miles away, and had been less than twenty-four hours in transit.

A still more striking and famous illustration is found in connection with the eruption of Krakatoa, a volcano in the East Indies, in 1883. The finer dust is reported to have ascended to a height of 17 miles, and is believed to have been carried around the world. To the presence of this dust is ascribed the lurid hue of the skies during the late summer and the autumn of that year.

These striking examples, remote from common view, should not lead us to neglect the importance of wind carriage as going on everywhere. Such transportation does not compare with that of streams, but in seeking to understand the history of the earth, and to know how it has become suited to human life, we must neglect nothing, for small causes at last achieve large results. An English geologist believes that the fertility of English soils is largely due to the winter and March winds, especially when we remember that the climate of glacial times was colder and the soil less protected by vegetation. He cites cases of church towers, even in marshy regions, upon whose top enough soil has lodged to support growing plants.

5. **Deposition by winds.**—The dust, swept over all continents and seas, is as constantly deposited upon land surfaces, or is sinking to the sea bottoms to mingle with other materials there accumulating. But in favorable situations much dust comes to repose locally, forming hills known as sand dunes. These hills may be steep in slope and limited in area, or they may stretch with gentle undulations over a considerable territory. The conditions for dune-making are abundance of fine material, lack of plant covering, and strong winds. It is plain that these conditions are often met in desert and shore regions. In shore belts the grinding of the waves produces the material and prevents plant growth, while the winds sweep unhindered over the waters. The dryness of the air and disintegration of the rocks effect similar results in deserts. The dune hills may lie in ridges with intervening hollows, like a succession of waves and troughs, or they may be disposed in an irregular and disorderly way. They vary in height from a few feet to more than 200. The inclination of their surfaces is often gentle on the windward side, but may be quite steep on the lee side, since the sand falls over the crest and comes to rest at the steepest angle which such loose material will assume. The surface often bears ripple marks, such as are made by waves in shallow water. Internally, if a cutting be made through the sands, they may show layers or strata due to deposition at different times, or by winds of different velocities, which would bring materials of various sizes. The inclination of the layers may show great variety, dependent on the direction of the original slopes which received them.

Scanty vegetation is often found on dune surfaces, and sometimes, as on Cape Cod, plants have been set by the hand of man to hold down the sands and prevent the devastation of cultivated fields lying beyond.

Fig. 2.—Dune encroaching upon open ground and forest.—After Cowles.

6. **Migration of dunes.**—Not only the sand grains, but the dunes, may travel for some distances. The wind picks up particles on all parts of the exposed slope and carries them over the crest. It is evident that the crest and lee slope will slowly advance in the direction of the wind. Illustrations of this process will be found in the following paragraphs upon the distribution of sand hills.

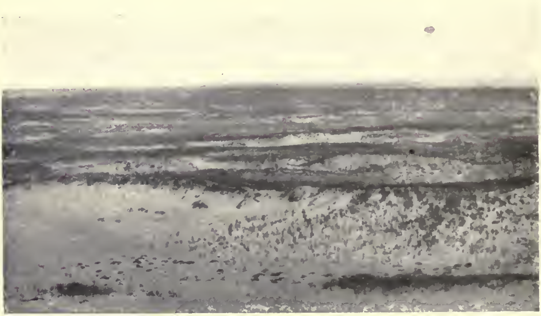


FIG. 3.—Sand dunes, north from Monomoy Lighthouse, Cape Cod. (Copyright by S. R. STODDARD, Glens Falls, N. Y.)

7. **Sand dunes in shore regions.**—Dunes abound along the eastern coast of the United States. On the shores of Massachusetts and Long Island much fine earthy *débris* was deposited by glacial ice. This is easily worked over by the waves, and becomes the sport of the winds. Extensive dunes are found north of Cape Ann, along the outer shores of Cape Cod, and on the islands of Nantucket and Martha's Vineyard. Readers of H. D. Thoreau's Cape Cod will find graphic accounts of the wind-blown sands. Dana notes the presence of sand ridges for 100 miles along the shore of Long Island. From New Jersey southward the lands consist of marine muds and sands lifted above the

sea level in late geological time. Hence they are relatively loose deposits, readily crumbled by the waves, and built by the winds into sand hills.

The Bermuda Islands, whose highest hills have an altitude of more than 200 feet, are, from a few feet above the sea level, eolian formations. Calcareous sand, fragments of corals, and shells ground up by the waves, are

Fig. 4.—Beds of limestone deposited by wind, shore cliffs, Bermuda Islands. Photograph by W. G. C. Kimball.

thus effectively used by the winds for the making of land. Rain waters carrying lime in solution have cemented many of these sands into hard rock, which may be seen in quarry walls and in the rugged shore cliffs of the islands.

Many good examples occur on the shores of Europe. Abundant dunes are found on the exposed coast of Norfolk and Cornwall in England. In the latter district a church was for seven centuries smothered in the migrating sand hill, but came to light in 1835. On sections of the French coast the dune belt has an average width of 3 miles, and, according to Prestwich, is advancing inland 30 to 60 feet in a year. On the west coast of France streams have been forced by the encroaching drifts to wander along the shore, seeking an outlet to the sea. In Denmark the migration of the dunes has in some places been checked by planting groves of pine trees. Holland has a belt of shore dunes ranging from 50 to 260 feet in height, and from 1 to 5 miles in width. Writers on the geography of Palestine describe the "endless mounds of drift sand" which impede tillage and have mantled the ruins of the ancient Philistine cities of the Mediterranean.

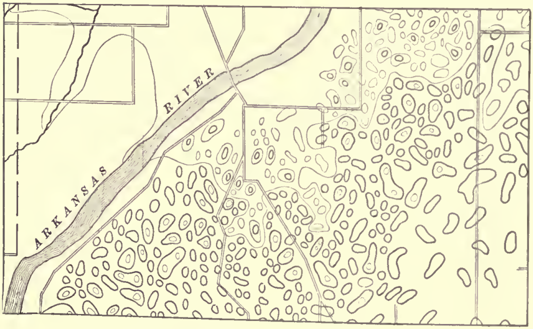



Fig. 5.—Sand dunes south of Kinsley, Kan.
Scale, one mile to the inch. Contour interval 20 feet.

Extensive dunes may be formed along lake shores. Travelers entering or leaving Chicago on the east may see many such hills, sometimes entirely bare of vegetation, as at Michigan City. Mammoth dunes are found in Michigan on the eastern shore, at Grand Haven and other points.

8. **Dunes in arid regions.**—Wide stretches of dune country may be seen in western Kansas (see map), Nebraska, Colorado, Wyoming, and Arizona. The same occur in the Sahara, and in the vast plains of Central Asia. A striking geographical result of drifting sand is the changed course of the river Oxus, which, having formerly flowed into the Caspian, now enters the Sea of Aral. Drifting sands of deserts are greater in amount than those of shores, but are less conspicuous in their relation to human interests, and have not been so widely observed and described.

9. **Loess.**—In the Mississippi and Rhine valleys, and in the high basins and on the plains of central China, are great deposits to which this name has been given. Nearly all observers agree that the winds have had much to do with the present character of these great sheets of earthy matter. The typical loess in China and other regions is a yellowish or brownish earth or loam, without stratification, and sometimes attaining a thickness of more than 2,000 feet. It has, however, a vertical structure of fine tubes, believed to be due to the roots and stems of plants occupying the successive surfaces as the deposit has grown. Thus there arises a cleavage by which vertical cliffs are formed along streams and highways, dissecting the country into a labyrinth of plateaus and narrow valleys. The peculiar characters of the loess lend themselves to human uses in an interesting manner in China, as thus described by Pumpelly:

"This remarkable combination of softness with great strength and stability of exposed surfaces is of inestimable value in a woodless country. In Asia thousands of villages are excavated in the most systematic manner at the base of cliffs of loess. Doors and windows pierced through the natural front give light and air to suites of rooms, which are separated by natural walls and plastered with a cement made from the loess concretions. These are the comfortable dwellings of many millions of Chinese farmers, and correspond to the rude 'dugouts' of Nebraska."

Fig. 6.—Quarry in limestone formed of blown sand, Bermuda Islands. Photograph by W. G. C. Kimball.

In the Mississippi valley the beds have less thickness, and are believed to be first due to flood streams from the continental glacier.

These streams wandered widely over low grounds, and deposited fine materials brought from the north. These materials have since been worked over in large measure by winds. Similar deposits are found in Utah, Nevada, and California, and are ascribed primarily to the transporting action of streams, which carry rock flour from the surrounding mountains and spread it over the plains.

10. **Indirect geological effects of winds.**—Here we observe (1) the making of waves on oceans and lakes, the waves in turn working important changes along the shores, as will appear in later chapters. (2) Transfer of water vapor. Such vapor arising from bodies of water overspreads the lands by means of winds, giving rise to streams of water and ice, the most effective of geological tools. (3) Transfer of heat, directly and by means of ocean currents, determining the groups of animals and plants which shall occupy the lands and seas, and thus in turn modifying soil formation, denudation of land surfaces, and powerfully controlling the life of man. We have here a good illustration of the blending of causes and effects in the history of the earth. (4) Carriage of seeds and other organic forms. Many plants have seeds or stems which adapt them to such movements, as the dandelion, or the Russian thistle infesting the plains of the Northwest. Birds are swept from continents to islands, or from one continent to another. McCook describes a species of spider which has thus come to inhabit the circuit of the globe. Darwin many years ago collected dust on shipboard, nearly or quite 1,000 miles from the African shore, and the dust was found to contain multitudes of lowly microscopic organisms brought from the land. We may safely say, therefore, that the indirect geological effects of winds are greater than those which they accomplish immediately.

# CHAPTER II

## WEATHERING

11. If we observe a ledge of rock naturally exposed in a hillside field or on the banks of a stream, we shall find evidences of decay. The outer parts are commonly discolored, cracked, and may even crumble under the pressure of the hand. If the slope is steep, pieces will have fallen off, to form a heap of coarse or fine rubbish at the bottom. In like manner, if we examine rock which has been artificially exposed for some years, we shall find the beginnings of decay, as in railway cuttings or upon stone fences or buildings. Flakes scale off, corners become rounded, scars and cracks appear, and an aspect of age is taken on. Let us visit also a sand bed or gravel pit. We shall be likely to see at the top a thin layer of dark soil with roots, then more or less loamy, brown or yellowish earth, and below, the undisturbed, often bluish beds of sand and gravel. The upper beds have suffered changes of color, constitution, and form from which the lower beds have been free. We may also study with profit a heap of cobble stones gathered out of a field. Some are hard and apparently unchanged, or, if decay has begun, only the outer film is affected. Others break up with a slight blow, or may be shaven fine with a pocket knife, showing that some rocks yield more easily than others to destructive agencies.

To the processes of which several illustrations have now been given, the comprehensive term *weathering* is applied. The term expresses the sum total of changes which come to a rock mass under exposure at or slightly below the surface of the earth. The process is a highly composite one. Air, water, heat, and other agents are at work, and we might distribute their effects under the great divisions of dynamical geology. But the processes are so general, so

FIG. 7.—Magog, Pike's Peak trail. Bowlders formed in place by weathering.

linked together, and so important, that we must at once take a comprehensive survey of them. The central fact in the earth's history is that rocks in all lands are in process of destruction, and in all seas are being made anew. It is necessary for us at once to see that destruction of rocks is quietly going on everywhere, and hence we proceed to a fuller account of weathering.

12. **Definitions.**—A *rock* in geology is any aggregate of rocky or earthy matter, whether consolidated or not. As

thus defined, rock includes sands, clays, peat beds, and soils. Rocks are often in beds or layers, and are said to be *stratified.* In undisturbed regions the beds are nearly horizontal. Planes of division often intersect the beds in a nearly vertical direction. These are called *joints.* A wall-like mass of rock in a molten condition is sometimes intruded into a crack in other rocks. It may vary in thickness from a fraction of an inch to many feet, and is called a *dike.* A rock that is largely composed of carbonate of lime is a *limestone.* A rock made up of broken grains of older rocks bound together by a cement is *sandstone.* Fine flour of older rock masses compacted again into rock is a *shale.* Limestones, sandstones, and shales show endless variety of constitution, texture, and color. These, and other rocks which are less common in most regions, will be described in Part II.

## Weathering Agents

We will now study certain substances and forces in their relation to weathering. While we must take them up one by one, it is important to remember that several of them may be operative at the same time upon a given mass of rock.

13. (1) *The atmosphere.*—Dry air has little direct chemical effect upon rocks, though its oxygen may to a slight degree combine with some elements of rocks, and thus by slow combustion contribute to their decay. The nitric acid and ammonia of the air are small in amount, and, according to Merrill, are of slight account in weathering. The carbon dioxide is more important, and with the oxygen becomes an effective destructive agent in connection with water.

14. (2) *Water.*—The blows inflicted by raindrops, especially in a violent shower, have considerable erosive effect upon unconsolidated rocks, such as soils, sands, and clays.

Little by little the surface portions are broken up and carried away by the rills which are formed. Thus we come to the work of running water, to be studied in the next chapter. The efficiency of rain is due to its constant and

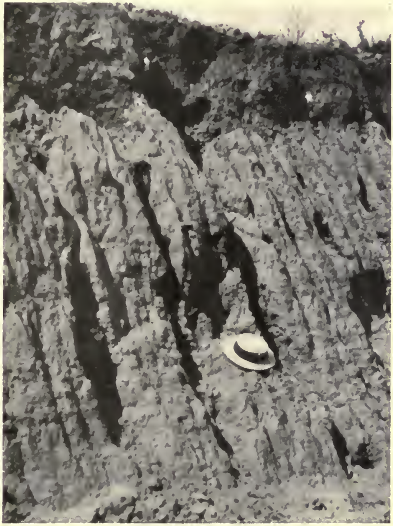


FIG. 8.—Rain erosion, Garden of the Gods, Col. Photograph by the author.

widespread action. We must remember also that there are regions of violent and prolonged rain, in which from two to ten times as much moisture falls annually as in the northern United States. Considerable pillars have been formed by rain out of stony clay. The stones protect the clay beneath from wash, and thus cap the rude columns which are formed by the carrying away of the surrounding mass. Sometimes these pillars are many feet in height.

The water which exists in the air as vapor, and that which filters through the surface layers of rock and soil, does its geological work mainly by chemical changes. Among these changes *solution* is one of the most important. Pure water has a solvent effect upon all rocks, even though it be slight. But water in nature is never absolutely pure—that is, without other ingredients than its constituent hydrogen and oxygen. It gathers to itself acids and gases of various kinds, which enable it slowly to eat away rocks and take their par-

FIG. 9.—Erosion columns made by the weathering of stony clay. Note the protecting bowlders.

ticles into solution. Nearly everywhere the earth is covered with a mantle of decaying plants. Such decay causes the formation of substances known as the humus acids.

Water soaking through the soil takes up these acids and thereby dissolves the rocks. Most important of these is carbon dioxide, which is gathered not only from the soil, but from the atmosphere by the falling rain. Water containing this gas dissolves many substances effectively, especially carbonate of lime. If rocks largely made up of this or other soluble minerals are subjected to the action of carbonated waters, the soluble matters are washed away, leaving what is known as a residual soil. Thick beds of rock are sometimes greatly reduced by this process. A number of illustrations will now be given to show the geological importance of solution. Some of these are quoted from Merrill.

In Arkansas, analysis of a sample of fresh limestone and of clay left as a remnant by solution, showed that over 97½ per cent of the original rock has disappeared. A marble clock case packed in damp excelsior from May to October required repolishing. Over many narrow bands where the fibers rested the surface had been sufficiently dissolved to destroy the luster. Various minerals digested for forty-eight hours in carbonated waters gave off from 0.4 to 1 per cent of their mass.

If we now remember that limestones extend over wide areas, and that acidulated waters are always flowing over them and soaking through them, we shall see that solution is vastly important in geology. It has been computed that 275 tons of lime carbonate are annually removed from each square mile of limestone country in the Nittany Valley of central Pennsylvania. Another estimate gives the annual removal of all soluble matters by solution from the surface of England and Wales as 143.5 tons per square mile. The meaning of these facts as regards the general reduction of land surfaces will be considered in the following chapter. The effect upon water supply is one of the most important results of solution. If the surface materials contain much lime, the water will be "hard," as it is termed, encrusting tea kettles, and will be unfit for some domestic uses. Many regions of less soluble rocks are overspread by limestone flour produced and transported by glaciers and readily soluble by surface waters. In Scotland, Loch Katrine lies in a

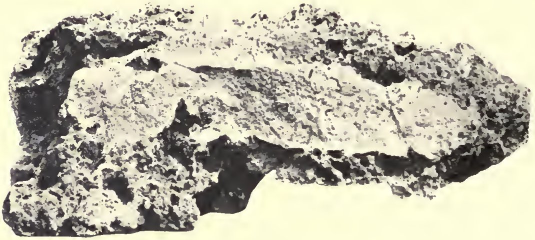


Fig. 10.—Calcareous sandstone, showing weathered sandy rim and a solid core which contains the original carbonate of lime.

region of less soluble rocks, and hence furnishes soft water to the great city of Glasgow. The same, according to Ramsay, is true of districts in northern England, whence Liverpool, Sheffield, and other cities are supplied. On the contrary, the waters of the south and east of England, derived from the chalk and other limestone formations, are very hard. The Bath Old Well sends out enough lime in its waters in one year to make 304 cubic yards of limestone.

A rock may consist mainly of minerals not easy to dissolve, cemented together by a small amount of soluble material. Some sandstones consist chiefly of grains of quartz bound together by a very small percentage of lime. The solution of the latter may cause the entire mass to crumble.

The oxygen of water often unites with materials of rock and causes decay. This process is known as *oxidation*. Oxygen unites very readily with iron, causing slow combustion, producing "rust," and leading to the disintegration of the rock which contains it. Oxidation is perhaps comparable in geological importance to solution.

*Hydration* (literally watering) is also important in some cases. Rocks may take water into union with one or more of their constituent minerals, which are thereby increased in bulk, and strains are set up by which the coherence of the rock is injured and it may disintegrate.

Fig. 11.—Talus from fallen block, Ouray and Silverton Toll Road, Col. Photograph by the author.

15. (3) *Heat and cold.*—Rocks, like other substances, expand upon receiving heat and contract when it is withdrawn. The outer portions of a rock mass are subject to

greater alternations of heat and cold than those which lie beneath, and surface parts are likely to flake off. Observations have shown that Bunker Hill Monument is swayed during a sunny day by the greater expansion of the heated side. The movement is slight, but in the course of centuries will contribute toward the destruction of the pile. Dr. Livingston reported from Central Africa the effective rending of rocks which were raised to a temperature of 137° during the day, with abrupt loss of heat at night. Geikie observed 90° and 20° as daily extremes of temperature in the Yellowstone Park. In the same region Merrill saw fresh chips of black rock, made in this manner, but bearing much resemblance to the handiwork of man. Such daily variations of temperature do not commonly extend below three feet from the surface, but annual variations, as between winter and summer, affect the rocks at much greater depths.

It is here convenient to consider the breaking of rocks due to water freezing in crevices, as along bedding or joint planes, or fractures. Freezing water at a temperature of 30° exerts a pressure of 138 tons per square foot. It thus becomes a resistless rending agent. At the brow of a cliff blocks may be frequently found to be wedged off from a part of an inch to a foot or more. The opening, narrow at first, is filled only by water, afterward by water and soil, which expand with freezing, giving the adjoining rocks a slight but effective push which eventually carries their center of gravity beyond the point of support.

16. (4) *Organisms.*—The general effects of living forms in modifying the surface of the earth will be set forth in a separate chapter. We must here briefly notice their contribution to the disintegration of rocks. Falling leaves and the decaying trunks and branches of trees and herbaceous plants cover the earth with a more or less complete mantle of vegetable mold. Numerous acids are produced by this decay and are contributed to the rain water

which soaks into the ground, thereby greatly increasing its solvent power. Similar effects are produced by lichens and other lowly plants, which attach themselves to rocks, keeping their surfaces moist as well as supplying destructive acids. The crumbling surface of stone walls will offer abundant illustrations.

Mechanical rending of great importance results from the growth of roots and trunks, which establish themselves in crevices and push apart the adjacent masses of rock with almost resistless force. Wherever trees grow on the edges of a ravine or in fields where rocky ledges protrude from the scanty soil, such work may be seen. Even young and succulent roots are effective in this manner, and hence the process is almost universal.

Plants may retard weathering by interfering with the conduction of heat and by the formation of even temperature, and also by protecting surfaces from the action of winds.

17. (5) *Gravitation.*—All earthy and rocky matter shows what we may call the downhill tendency, unless supported by surrounding masses. Energy is thus applied so widely and so silently that its immense importance in geology is commonly overlooked. From the crests of waterfalls and the borders of deep cañons great masses may fall. This is more conspicuous but less important than the steady downward "creep" of stones and soil on all slopes. The presence of moisture relieves the friction between particles, and a direct offthrust is made by freezing water. Slight slips give rise to small benches running along the face of slopes. These are more often due, however, to the tracking of sheep or cattle. Under favorable conditions such movements are extensive and sudden, and we term them *landslips* or *landslides.* These will be noticed in describing the work of subterranean waters.

Here we may class the effects of avalanches or great snow slides in mountain regions. On the high slopes of the San

Juan, about Silverton, Colorado, open lanes descend between belts of forest, being the track of avalanches. The uprooting of trees exposes the soil to removal and may determine a water course. A great number of such ava-

FIG. 12.—Angular waste, timber line, Pike's Peak trail.

lanche tracks may be seen in the Alps, and the Swiss people drive wooden piles in ranks on the slopes to break the force of the slides. Avalanche snows often outlast the summer at the base of cliffs.

18. (6) *Electrical discharges.*—These are, so far as present investigations have gone, a minor agent in weathering, although they are of considerable interest. If the discharge has passed through sand or through consolidated rocks in exposed situations, small branching tubes lined with glassy material may be found descending into the

earth. The glassy lining is caused by the melting of the minerals composing the rock or sand in the path of the current. Such tubes are called fulgurites, and have been found on the summit of Little Ararat and in the Cascade Range of Western America. An irregular train of fulgurites has been found leading off from a tree which was

Fig. 13.—St. Peter sandstone, Iowa. Effects of joints and bedding planes on weathering. From Iowa Geological Survey.

struck by lightning in Florida. Sometimes glassy patches or beads are formed instead of tubes. Electrical shocks may extensively shiver rock masses among high mountains.

**19. Favorable conditions for weathering.**—It is evident that the weathering agents will vary in their efficiency and grouping. It is important for the student to recognize the interplay of the several forces and their widespread action. Rocks crumble much more readily because of the bedding and joint planes which intersect them. A perfectly solid mass of rock would be attacked with difficulty except at the surface. As it is, the thickest formations and greatest mountains yield to the silent industry of Nature's tools. Water and air surely find the smallest openings in the rock, and there can be but one result. Geologists are not agreed as to whether rocks weather more readily in warm or cold climates. It may be safe to say that chemical decay proceeds more rapidly in warm regions, where vegetation decays rapidly and solution is active; while mechanical disintegration is more favored in temperate and arctic climates, with their powerful frosts and large variations of temperature.

## Effects of Weathering

20. (1) *Color of rocks.*—The color of rock masses assumes almost as large variety as is found in the vegetable world. Brown, blue, green, gray, yellow, and red, in all shades and combinations, come before the eye of the geologist until they baffle description. Pure black and white rocks are not very uncommon. Tones are usually neutral and harmonious, though brilliant effects are sometimes seen, as among the Colorado plateaus.

Color is due in part to the minerals originally composing the rock, and in part to later changes. Some of these changes fall under the head of weathering. Thus the clay at the top of a pit may be yellow or brown, while at the bottom it is blue, because there protected from water, air, frosts, and the penetration of roots. According to Merrill, the Berea sandstones of Ohio are gray or bluish gray below the drainage level of the quarries, and buff above. In a great number of cases the color of rocks is dependent upon changes produced by the exposure of the compounds of iron which they contain. Some soils of nonglacial regions have a prevailing red color. Some sands and gravels lying

FIG. 14.—Vertical strata near Manitou, Col., showing down-hill creep and the weathering of hard and soft layers. Photograph by the author.

beneath peat beds have been perfectly bleached, the iron in them being made soluble by the vegetable acids descending from the peat.

21. (2) *Soils.*—Weathering is largely instrumental in the formation and exhaustion of soils. The term soil is often loosely applied to the whole sheet of crumbled rock material which mantles most of the rocky foundation of the lands. The thickness of this mantle varies from zero to several hundred feet. It is produced by the disintegration

and decay of rocks, and is largely due to the forces whose total effect we have called weathering.

But the term soil is better restricted to the thin layer of fine, dark material which chiefly supports plant life. It is finer because more thoroughly weathered and broken down. It is dark in color chiefly because of the decaying vegetable matter which it contains, and without which it could not be a true and productive soil. Soils may be largely derived from the decay of the underlying rocks, or they may be partly composed of matter brought from a distance. Pebbles and bits of mineral and rock constantly break up and furnish the soils with fine, soluble material which the rootlets of plants can use. Weathering is thus directly essential to the support of living creatures on the earth. On the other hand, some of the weathering processes may be destructive of soils. Thus by solution the soils of a limestone country may at last require the artificial application of lime. Small parts of the soil-cap are constantly removed, especially on sloping fields, and the soils would in the end be destroyed but for the renewal which takes place through weathering.

22. (3) *Appearance and durability of building stones.*— When stones are removed from their protected situation in the quarry and put into a wall, destruction begins. In the end no rocks can withstand it, though some are relatively permanent. The choice of building stones, therefore, is the choice of the better appearing and less destructible. But in all cases a few years will bring traces of decay. Obscure bedding planes and joints come to light, flakes peel off, changes of color ensue, surfaces grow dull, and after a time some blocks crumble and restoration is necessary.

Let the student discard the notion that any rocks are permanent. Let him observe the walls and buttresses of a stone church, or the approaches and fronts of a city block, or the monuments in a cemetery, and he will find many illustrations. The firmest granite is an aggregate of several minerals, which in time will break apart. The finest marbles are limestone, and therefore soluble. Sandstones are but clinging sands, and must crumble when the binding cement dissolves. Porous rocks which take up water are soon destroyed by changes of temperature. The obelisk,

Fig. 15.—Weathered remnants of inclined beds, Garden of the Gods, Col.

which was removed from the dry air and even temperature of Egypt, would soon crumble in Central Park without artificial protection. In Oxford, England, some college walls of the last two centuries have crumbled seriously, while portions of the cathedral and of some ancient defensive towers have stood for many centuries. Here the difference is in the material. Buildings may be everywhere seen in whose walls the blocks stand on edge and rapidly crumble, whereas if laid upon their natural beds, as in the quarry, they would endure indefinitely. Climate, choice of material, and manner of laying are therefore important considerations in building with stone.

23. (4) *Denudation.*—The removal of material and consequent lowering of a land surface is called denudation. As running water is the chief means of transport, the subject will be more fully treated under that head. But it is important here to observe that weathering is chiefly responsible for breaking up the rocky matter, rendering it accessible to the transporting agent. The earthy *débris* found everywhere over the rocky crust of the globe shows that the agents of removal can not keep pace with the process of destruction.

Disintegration can not proceed without limit if the material be not at the same time removed, because there is a limit of depth at which weathering agents are effective. But decomposition has gone on at considerable depths, as many observations have shown. We take the following from Merrill: "In the work of grading the streets in the extensions of the city of Washington, masses of strongly foliated granites, so soft as to be readily removed with pick and shovel, would be cut through, which yet showed every vein or other structural detail as plainly marked as in the original rock, and it was only by thrusting one's cane or other implement into it that its thoroughly decomposed condition became apparent."

Shale rock in Brazil is reported as turned into clay to a depth of 394 feet. According to Geikie, the kaolin arising from the decay of granite is sometimes found to a depth of 600 feet. These latter are somewhat exceptional cases. We must, however, remember that where removal occurs promptly strata many thousand feet thick may in succession disintegrate and be carried away.

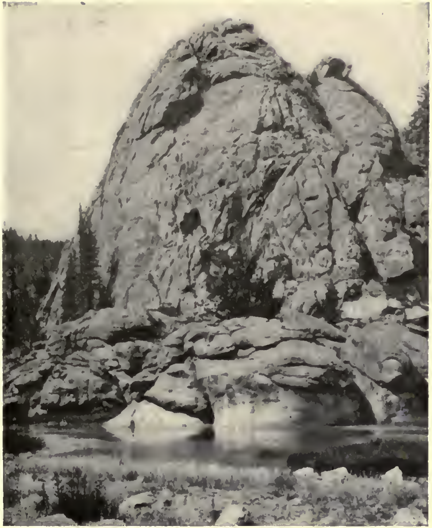


FIG. 16.—Weathered dome of granite, Platte Valley, Col. Compare Curricanti Needle, Fig. 17.

FIG. 17.—Weathered pinnacle, the Curricanti Needle, Col. Compare granite dome, Fig. 16.

In the study of weathering, mere disintegration by mechanical means, such as expansion by frost, should be distinguished from decay of a chemical sort, as by oxidation, although in Nature both processes go on together.

24. (5) *Topography.*—The evolution of land forms under the operation of all the geological forces will be treated in a subsequent chapter. But we must now call attention to the important effects which the varying resistance of the rocks produce upon the landscape. East of the Catskill Mountains the Hudson Valley is many miles in width. In the Highlands the valley sides rise abruptly from the edge of the water. This strong contrast in scenery is due to the ready yielding of the rocks to weathering in the Catskill region and the stubborn resistance of the tough rocks of the Highlands. Central Pennsylvania is a region of deep valleys alternating with mountain ridges. The rocks of the region have been more or less steeply turned on edge, and the soft beds have weathered and crumbled away, leaving the hard beds in high relief. The streams have had much to do with erosion here, and are wholly the means of carrying away the land waste, but the topography depends primarily on weathering. In the dry regions of the West vast piles of horizontal strata have been carved into remnants, often of fantastic form, making what is known as the "Bad Lands." Without a protecting mantle of vegetation, exposed to sun and frost, with occasional storms and spasmodic torrents for the transportation of *débris*, we have here also a conspicuous example of weathering.

Sheets and dikes of ancient lava are often either harder or softer than the rocks with which they are associated. They thus may cap "table mountains," so called, or form outstanding walls or sunken trenches, according to their relative degree of hardness. North and South Table Mountains, at Golden, Colorado, illustrate the former case, and some lakes and river channels of the Hudson Bay region

Fig. 18.—Bad Lands on North Platte River, Neb. Photograph by N. H. Darton.

are examples of the latter. The remnants of horizontal beds above mentioned may dwindle until they become very narrow and frail, as may be seen in the dells of the Wisconsin River and many parts of the Rocky Mountain region. Those pillars at length fall, and the stones composing them lose their corners by weathering, and we thus have erosion bowlders, similar in form to some that have been rounded by waves and glaciers. A bed of limestone in a field unprotected by soil may weather along intersecting systems of joints until all the blocks are well rounded, giving us a field of bowlders which have been formed in place.

Fig. 19.—Erosion pillar with resistant cap. Conglomerate of Monument Park, Col.

# CHAPTER III

## RIVERS

25. **Definition.**—By rivers is here meant all waters flowing on the surface of the lands. In this sense a river includes not only the trunk stream, but all branches and streamlets from its sources to its issue in the ocean or inland sea. If several rivers are said to flow into another, as the Ohio and others into the Mississippi, this is a distinction for convenience. What we really have is one compound stream or river system. Strictly, also, many lakes are only temporary expansions of rivers, and hence all rivers truly terminate at the ocean border. As commonly used, a river denotes any considerable stream, and yet relatively, for many rivers of small countries would be called creeks or brooks elsewhere. Thus most rivers of Great Britain are small, and are important only because they are tidal near their mouths, and become thus the servants of commerce.

26. **Matter and energy.**—The chief principle of science is that matter and energy may suffer changes of form, but are in themselves indestructible. Thus water may be found as vapor, as liquid, or as solid, having in each condition its appropriate geological effects, but no atom is ever lost. So also force, seen now as heat, may reappear as light, electricity, motion, or chemical reaction. By the sun's heat water is evaporated, chiefly from the ocean, in less degree from the lands; the vapor is borne over land and sea by the winds, is condensed by cooling, and falls as rain, snow, or hail. The gathering of the raindrops on the

earth's surface gives origin to rivers. The rivers run to the sea, and on their course accomplish the most important work which the geologist has to study. It is well here to observe that the force applied appears first as heat expended to raise the water, and reappears in the fall of rain and flow of streams. We speak of the geological work of rivers, but we really deal with force in the forms of heat and gravitation, of which the watery matter is only a medium of application.

27. **History of a drop of rain water.**—If water lifted from the sea falls directly back, it has no geological function save as a part of the sea, whose work we shall later study. If carried over the land, it may be re-evaporated in the course of its fall, or it may reach the surface of the earth. In the latter case the geological activity begins. It may soak into the ground, and, after a passage more or less long and deep, emerge in a spring and become part of a river; or it may be taken into the tissue of a plant and be re-evaporated into the air; or it may run directly off, helping to form a rill and then a river. It is the last case with which we are now concerned. When the drop of water has passed from the sea to the clouds, has traveled over the lands, fallen to the earth, and returned by a river to the sea, it may be said to have passed through a cycle of activity.

28. **Rainfall and run-off.**—The amount of rain that falls at a given point depends upon its nearness to the sea, upon the latitude, altitude, temperature, surrounding topography, and other conditions. In the eastern United States the annual rainfall is from 40 to 50 inches. In much of the West it is about 20 inches or less. In England and Wales the amount is about 32 inches. Along the north Pacific coast of America, on some South American borders, and in parts of India it is more than 100 inches. In the latter region at some points more than 30 feet per year fall. Much of the rainfall soaks away, or is at once evaporated. The "run-off" only is available for stream work, and the

percentage is variable, depending on climate and soil. According to Dana, one third to two fifths of the rainfall runs off in the temperate latitudes. One fourth is the proportion for the Mississippi basin, and one third for that of the Seine. In very dry regions the percentage is much less.

29. **Parts of a river.**—A large river which drains areas of continental extent shows great variety in its different parts. We may call such a stream a typical river. The Amazon, the Rhine, and the Ganges are good illustrations. They rise in high mountains, flow swiftly down narrow gorges, cross the lower lands by spacious valleys, and swing easily over broad alluvial plains to the sea. Geikie has called these parts the mountain track, the valley track, and the plain track of a river. They show infinite variety in form and relative length, and one or more of them may be absent. Thus the Susquehanna and the Red River of the North do not rise in mountains, though there are precipitous ravines at some sources of the former. The western Andes also are drained by torrential streams which pass almost immediately to the sea. In the median or valley track of a single river great difference may appear, dependent on rock structure. Thus the Yukon is a case in point. The valley track is many hundred miles in length, "bordered in places by magnificent bluffs of hard rock, which intervene between long reaches where the valley is several miles broad and has been excavated in softer beds." Similarly, quiet reaches of a river alternate with rapids and waterfalls, and sections of a river are by various means transformed into lakes.

30. **Vigor and continuity of river action.**—The best evidence of this is in the facts which follow. A river is the most active, varied, and we may almost say vital thing in the realm of inorganic nature. In the making up of new lands, the remodeling of the old, and in its control over human life, it is pre-eminent among geological facts and forces.

FIG. 20.—Torrent courses and waste slopes, with avalanche snows, Guttannen, Switzerland.

## Erosion by Streams

31. **Definition and examples.**—The most general term for the depression through which a stream runs is valley. A valley may be deep or shallow, wide or narrow, and may have steep or flaring sides of various form. A narrow, deep valley may be called a gorge (gullet), gulch, ravine, or cañon. The term ravine refers to the violent, tearing action by which such a valley was made. The term cañon is of Spanish origin, and is most commonly used of the deep gorges of the West. That most valleys are due to the rivers which are flowing in them was not appreciated until the earlier part of the nineteenth century. Now it seems axiomatic that the Connecticut, Susquehanna, and Ohio valleys, and the gorges of Trenton, Niagara, and the Colorado, are mainly due to stream erosion. We shall now inquire how such work is done.

32. **Means of river erosion.**—Water which carries no suspended rocky matter may erode a considerable channel in soils, sands, or gravels, especially if the current be swift. It would thus, however, pick up tools which would enable it effectively to cut into the harder rocks. Every particle of rock serves as a rasp when driven by the current against the rocks at the bed or border of the stream. The friction of contact wears away small fragments, and by long continuance the action accomplishes much deepening and widening of the channel. The water of Niagara River has lost its load of rocky *débris* in the quiet waters of Lake Erie, and hence has scarcely sunk its channel below the surface even by the raging torrent of the rapids above the fall. The great erosion accomplished below the falls is due to special conditions which will hereafter be explained. In like manner the St. Lawrence, receiving the clear waters of Lake Ontario, accomplishes little erosion at the Thousand Islands. The Connecticut, on the other hand, loaded with waste from the mountains of New England, has excavated

a great valley. Sandy matter wielded as an erosion tool by flowing water is analogous to similar material driven by a stream of air in the natural sandblast.

River erosion is also favored by the presence of joints and bedding planes. These planes are opened by solution and by mechanical wear as above described, so that it is no uncommon thing to see the bottom of a stream paved with rectangular blocks more or less isolated from each other. Water in portions of shallow streams is often frozen to the bottom in winter. The ice attaches itself about the blocks of rock and in the floods of the spring buoys them up, or at least aids the swift current in dislodging them. They are then tumbled against one another, subjected on every side to filing and solution, to alternations of moisture and dryness, heat and cold. Thus weathering co-operates with the direct work of streams. Particularly do the solvent processes at all times accompany the more obvious mechanical disintegration which takes place. That events do not proceed from a single cause, but are rather the resultant of many forces, is a cardinal principle in geology. For convenience we treat one process at a time, but we must remember that other processes are always at work.

33. **Overloaded streams.**—As we shall see, in studying the transportation of rivers, streams sometimes carry a great burden of earthy matter. The waters are loaded to their full capacity, and no energy is left for erosive work. A medium amount of transported material therefore gives to flowing water its highest abrasive power.

34. **Mutual abrasion of particles.**—Transported fragments wear off particles from the rocky bed of streams, and in turn suffer loss themselves, not only by friction against the bottom but by being rubbed upon each other. Vast quantities of rock flour or fine mud are thus made and strewn along the valley and eventually carried out to sea. Experiment has shown that when pieces of granite and quartz were rolled over each other in water through a distance of 15½ miles, the

Fig. 21.—Narrow gorge in horizontal strata, Ausable Chasm, N. Y.
(Copyright by S. R. Stoddard, Glens Falls, N. Y.)

fragments of granite lost four tenths of their weight and became rounded like river pebbles. The water was filled with a very fine mud, which remained suspended for several days. Cubes of rock placed with water in a revolving receptacle will become almost perfect spheres, the "marbles" of children's play. The banks and shoals of swift streams will supply abundant illustrations in pebbles of remarkably symmetrical forms, which can sometimes be traced to their sources up the stream, and the distance of transport can be thus determined. At points along the Rhine, according to Geikie, the grinding of the pebbles upon each other can be heard by an observer who holds the ear to the bottom of an open boat.

35. **Down-cutting by streams.**—We are now ready to see how a river deepens its channel and is ever sinking its bed toward the sea level. The higher the river bed above the sea, the greater is the average velocity of the stream and the force with which it applies its erosive tools. Hence valleys are commonly deepening most rapidly in mountains and near the head waters of streams. Perpetual filing of surfaces and upturning of slabs and blocks of rock bring the sure result. Under certain conditions slush and ground ice or anchor ice form at the bottoms of streams and aid in floating stones which are more or less inclosed by it. Valleys are deepened in an important way by the recession of waterfalls. Along swift portions of a stream the formation of *potholes* aids in sinking the channel. At such points sharp eddies form with a downward spiral movement of the waters. The eroding implements are wielded with especial effect in such situations, and a depression is readily hollowed out in the bedrock beneath. As this deepens it catches and holds stones of considerable size, which maintain their gyrating movements even after the pit becomes deep in proportion to its width. The work often goes on vigorously in the spring, while in summer and autumn we find pools of still water, at the bottom of which the rolled stones may be seen.

These are continually worn out, and others from up the stream take their places. The pits may attain a depth of 20 to 30 feet, and the diameter will vary from a few inches to many feet. Potholes of 10 feet in depth may not have a maximum diameter of more than 2 feet. If layers of variable hardness are encountered the diameter may show abrupt variations. At Little Falls, N. Y., where the waters of the Mohawk descend over hard rocks, there is a noteworthy display of potholes. Some are 20 or 30 feet in diameter, irregular in form, as if several adjacent pits had been merged into one by the wearing out of their bounding walls. Another of 20 feet in depth opens at a height of 60 feet above the river, proving in an interesting manner the former presence of the river at that altitude. Similarly a curve of large radius is often hewn out of a cliff at the base of a waterfall.

36. **The widening of valleys.**—By downward erosion along a belt covered by the stream at a given time, only a narrow gorge could result. But other factors enter in to give a valley width. Here we have to do partly with weathering and partly with the behavior of the stream. It is not quite true to say that a river makes a wide valley, though it is the chief instrument. Solution on the borders of a stream, the offthrust by frosts and by roots of trees, the burrowing of animals and the creep of soils, have greatly to do with the result and should have wider recognition as agents in valley making. Returning now to the direct action of the stream, we observe that the river tools not only file the bottom, but the banks, and thus widen the channel. Wherever ice forms over rivers it carries off attached rock fragments from its borders, and exerts a stupendous grinding and plucking force as it breaks up. A similar but quiet thrust is exerted when the ice shrinks and cracks in time of intense cold, and water fills the cracks and expands as it freezes, the whole mass being thus thrust outward against the banks.

We have now to notice the most effective way in which a river widens its valley. It is constantly grazing with greater force on one or other of its banks. This is true in all valleys, but more obviously in those which have considerable width, where the stream swings to and fro, cutting a curved slice now out of one bank and now out of the other. The location of the curves shifts from time to time, and thus in the end the sides of the valley are encroached upon at all points. Steep bluffs, describing a curve, may often be seen at some distance from the stream. A swamp or lagoon below the bluff marks the recent presence there of a river, which is now at work at another point. In time such bluffs are softened by weathering, and become a part of the flaring walls of an old valley.

37. **Limits of vertical and lateral erosion.**—Whenever a river or a part of it attains the sea level it ceases to sink its channel, and is said to have reached its *base level* of erosion. Base level is an important term and means the level below which subaërial erosion can not take place. This limit is practically reached when sea level is approximated and the stream becomes sluggish. The process of widening will, however, continue. Thus the Connecticut River is close to base level throughout its course across Massachusetts and Connecticut, but is yet actively widening its valley in those States, while farther north vertical as well as lateral erosion is vigorously carried on. If a stream crosses a resistant barrier, its bed for some distance above will in time wear down to this level, which may be called a local base level. Thus a river may descend to the sea by several sections resembling steps, in each of which deepening is slow and widening is active. In time, however, all barriers will be cut away, and the ultimate base level be approached. Lateral erosion of a valley will continue so long as high ground remains between it and its neighboring valley.

38. **River erosion not continuous.**—This is true whether we consider time or space. Streams often erode actively only

in time of flood. Nearly all the destructive work of a year may be done in a few days at the end of winter, or a few periods of heavy rain. Stream beds which are dry in August may be filled by a destructive torrent in April. Minia-

Fig. 22.—Headward growth of gorge whose lower slopes are wooded, Palenville Clove, Catskill Mountains.

ture cañons may be formed on a hillside during a single storm, crops are uprooted, and bridges and culverts are swept away. Disastrous results often follow a break in the banks of a canal. Repetitions of such effects during long periods in Nature are ample for making the gorges of the

Hudson, the Yellowstone, the Columbia, and the Colorado.

Nor does erosion go on throughout the extent of a river. It is active in the torrent section, intermittent in the valley section, and nearly zero as the river nears the sea. In the middle portions of the river deposit may go on at one season and erosion at another. Wherever the stream bed is composed of mud, gravel, and stones, we may have removal or deposit of these materials, but no cutting of the bed rock. If the under rock is exposed, we may know that solution is active, and that more or less mechanical erosion is going on.

### Transportation by Streams

39. Streams are the common carriers of the continents. According to their velocity and volume and the supply of material, they ever go loaded toward the sea, transferring the material of the lands to the marginal bottoms of the ocean. This process has long been recognized by man.

> "The waters wear the stones;
> The overflowings thereof wash away
> The dust of the earth."—Job xiv, 19.

> "The sound of streams that swift or slow
> Draw down Æonian hills, and sow
> The dust of continents to be."—Tennyson, *In Memoriam.*

40. **Derivation of load.**—The rocky materials are made ready for transportation in a variety of ways, partly by the destructive work of the stream itself as already described, partly by the entire assemblage of weathering agencies, very largely in some ages and parts of the world by glaciers, and sometimes by volcanoes and earthquakes. In some cases a stream is more than equal to the task supplied, and thoroughly removes the loose matter from its bed and border. At other times much material is supplied, and from lack of volume or velocity the stream, already

overloaded, leaves available material on its banks untouched and struggles along a clogged channel toward the sea. The Platte, flowing sluggishly for long distances through a region of crumbling rocks and soils, well illustrates this principle. Floating ice may be the means of transport both for fine materials frozen within it and for stones much too large to be moved by a stream of water unaided. A bowlder on the banks of the Yukon, six feet in diameter, was thus carried scores of miles from its parent ledge. Swift tributaries, which break up first in the spring, may sweep much *débris* down upon the still frozen surface of the main river. Avalanches and landslides in steep mountain valleys may accomplish similar results. No illustration of the carrying power of water is more valuable, however, than the wayside rill and rising meadow brook, clouded with land rubbish after every heavy rain. Within a few feet of each other points may be found where a sluggish current is moving only fine matter, and where a miniature torrent is pushing forward pebbles of considerable size. No observations can be more valuable to the beginning student than such simple ones which are possible to all.

41. **Transporting power.**—This depends upon velocity and volume. With enlarging rate of flow the size of fragments carried increases very rapidly. It has been shown that the transporting power of flowing water varies as the sixth power of the velocity. Increase of volume not only adds to the transporting medium, but increases velocity by decreasing the relative amount of friction between the stream and its bed. According to Dana, the size of fragments carried by currents of given velocities is as follows:

| Velocity in miles per hour. | Size of fragments. Diameter in inches. |
|---|---|
| $\frac{1}{8}$ | 0.016—fine earth or clay. |
| $\frac{3}{8}$ | 0.064—fine sand. |
| 2 | 0.6 —small pebbles. |
| 4 | $2\frac{1}{8}$ —large pebbles. |

FIG. 23.—Torrent bed, Isle of Skye, showing large bowlders moved in time of flood.

We have also to remember that the specific gravity of water is nearly two fifths as great as that of ordinary rocky material. Hence a stone immersed in water loses a large percentage of its relative weight, and tends to be buoyed up and easily borne along. Stones are often rolled over and over along the bottom, or borne up and on for a short distance, sinking to temporary rest again. But if materials are small and velocity large they may travel long distances without coming to repose.

42. **Amount of solids discharged by a river.**—Several classes of material must here be taken into account: (1) Matter held in solution; (2) particles held in suspension; (3) rock fragments too large to be suspended in water, but rolled or otherwise propelled along the bottom; (4) organic matter —remains of plants and animals. The facility with which acidulated waters dissolve carbonate of lime and other minerals has been considered under weathering. Much of this dissolved matter finds its way promptly into the surface streams and is carried to the sea. Russell has compiled the following table, showing how much matter is carried out in solution annually by well-known rivers:

| | | |
|---|---|---|
| Rhine | 5,816,805 | tons. |
| Rhone | 8,290,464 | " |
| Danube | 22,521,434 | " |
| Thames | 613,930 | " |
| Nile | 16,950,000 | " |
| Croton | 66,795 | " |
| Hudson | 438,000 | " |
| Mississippi | 112,832,171 | " |

Calcium carbonate leads all other substances, then follow magnesium carbonate, organic matter and silica, with smaller amounts of calcium sulphate, sodium sulphate, sodium nitrate, potassium sulphate, sodium chloride, and several others.

The amount of material carried in suspension varies much according to season and the rocks of the region. So also organic matter is very unequal in different places, being much greater amid luxuriant growths of warm climates. The Red River, according to Dana, was in 1854 obstructed by a timber raft 13 miles long, which was growing at its upper end, and breaking up and sending its materials to the Gulf at its lower end. But much more important than such isolated cases is the silent and constant carriage of twigs, leaves, grasses and roots, bones and shells, as well as decayed and dissolved organic matter. This is done by small and great streams everywhere.

Computations have often been made to show how much matter is carried in all these ways in a year by a given river. For this we must obviously learn the amount of water discharged and the percentage of solid matter in solution and suspension. To find the amount of water, we must determine the average cross section of the stream for a year near its mouth and the average velocity. The product of the two gives the amount of water. We now seek the percentage of dissolved matter (by analysis), the percentage of suspended matter (by allowing the particles to settle), and the amount pushed on the bottom (by estimate). Adding these and multiplying into the total discharge of water we have the desired result.

Such conclusions only roughly approximate the truth, but have been so often and so carefully sought that they may be received with some confidence. One of the most famous calculations of that sort deals with the Mississippi River, and was made many years ago under the direction of the United States Government. The conclusion was that enough solid matter is yearly transported to the Gulf of Mexico to make a column 1 mile square and 268 feet high, without, however, taking dissolved matter into account.

**Rate of denudation of land surfaces.**—With unceasing disintegration and transport of rocky matter, it is evident that land surfaces will be lowered toward the base level of erosion, if there be no uplift to offset the work of destruction. The time thus required to reduce a continent to sea level is a point of great geological importance. Interesting results have been reached, though it is not possible to remove sources of error and doubt. We must find the rate of removal as above, and the amount of matter to be moved. The factors of the latter are the area and average height of the continent or particular river basin. The product of these gives the amount of matter standing in relief above the sea, and this, divided by the amount carried in one year, gives the number of years required for reduction to base level if the rate were uniform. But we must remember that as the process goes on the land becomes lower, the streams lose velocity, both decay and transportation are retarded, and the rate of degradation steadily diminishes to the end.

We may arrive at the result in a slightly different manner, using our concrete case, the Mississippi. Taking the column of matter 1 mile square and 268 feet high, we divide the height by the number of square miles in the basin of the river (including all its branches), and find that a film of matter $\frac{1}{4920}$ of a foot thick is, on the average, annually pared away from the whole area. At this rate a foot would be taken off in about 5,000 years. If dissolved matter be also taken into account, as is desirable, Russell thinks the rate would be increased to one foot in 4,000 years. We can see, however, that in some distant future the plateaus of Kansas, Nebraska, and the Appalachian region would be worn down, the Kanawha and the Tennessee, the Missouri and Arkansas would lose much of their working power, and a foot of degradation would take a much longer time. This may be shown by comparing different parts of the United States as regards altitude and vigor of river action. The estimated mean height of certain States has been given as follows:

| | | | |
|---|---|---|---|
| Colorado ....... | 6,800 feet. | New York ....... | 900 feet. |
| Oregon......... | 3,300 " | Florida.......... | 100 " |

We may now contrast the *débris*-covered slopes and powerful torrents of Colorado and Oregon with the wooded summits and more moderate streams which prevail in New York. And in turn we may set the gorges of the Catskills and the Finger Lake region, and the swift waters of the upper Hudson, over against the crawling streams and slow degradation of Florida.

With the Mississippi we should compare well-known rivers in other lands. The rate of denudation for the basin of the Po is estimated at one foot in 729 years. The Rhone is believed to be lowering its basin at the rate of one foot in 1,528 years, and the Ganges one foot in 1,880 years. That stupendous transfers of matter from land to sea are accomplished by prolonged river action is a fundamental principle of geology.

## Deposition by Streams

43. **The law of deposition.**—That a stream drops its load in proportion as it loses velocity is the great law of deposition. If the loss be slight, only the coarsest parts of the load will sink to rest. If the loss be sudden and great, both pebbles and fine mud will be laid down together. Compare the sediment along a swift part of a rill with that which settles in its quiet pools. A stream may lose velocity by change of declivity, by various forms of obstruction, by overloading with land waste, and by entering a body of still water. From the nature of the deposits made, we may often read correctly the history of the stream that made them. The presence of minerals in solution in water results in a variable capacity to sustain and carry rock fragments. When a stream enters the ocean it deposits its load both because of loss of velocity and by reason of the salt in the marine waters, which hastens deposition. This can be illustrated by filling two glass jars, one with fresh and the other with salt water, and dropping a handful of earth into each. The general law of deposition above given

will be constantly illustrated as we study the various forms of deposit by streams. In this connection we are indebted to Prof. W. M. Davis for a useful phrase, which it will be well for the student to retain as a general designation of the several deposits: "The forms assumed by the waste of the land on its way to the sea." Thus all unconsolidated surface materials may be regarded truly as *en route* to the ocean. That they pause in a field or river bank for long periods, or that they may move with extreme slowness, as in the creep of soils, need not interfere with this conception, so long as the sea is the sure goal of land waste. Geology has ample stores of time upon which to draw for all her processes.

Soils are a form of land waste. Their origin and movements have already been noticed, and we may pass at once to those sloping banks of *débris* known as

44. **The talus.**—The word means literally *ankle*, and is applied in geology to piles of rock rubbish which have fallen at the foot of cliffs. The talus is not a stream deposit like those which follow, but it is so closely related to streams and stream work that it is convenient to study it in this connection. From every cliff fragments drop, being loosened in ways already described. If there be a powerful stream at the base it may carry away the material as it descends. Otherwise it accumulates in long, sloping banks under the cliff, and may be rough and stony or smooth and more or less covered with plants, according to the material. If the latter be coarse and angular the slope will be steep. If it be fine and rounded or dry the angle with the horizon will be less. The angle of inclination with a horizontal plane which loose material will assume is important. It is often called the angle of repose, and the student should accustom himself to determining it by measurement and by estimate.

Inclinations of 25° to 35° are common. If talus material is supplied rapidly from the cliffs, it may mantle the face of the latter almost to the top. The stream gathers its load from the lower edge of an adjacent talus, often taking out a considerable segment, leaving a very steep

FIG. 24.—Cliff and talus, Genesee Gorge, Rochester, N. Y. Contact of Medina and Clinton strata.

bank next the stream. A noteworthy talus is formed by the bowlders of trap rock which fall from the Palisades of the Hudson. Photographs of Western scenery will afford many good examples, and every steep bluff, sharp ravine, or gravel pit will give illustrations for study.

A succession of cliffs alternating with platforms, as on the sides of some cañons and mountains, will give a succession of taluses. As the material works down by frost and "creep," it may descend over successive cliffs and taluses until it reaches the drainage stream. As the several cliffs yield their material and are worn away, they will be more and more obscured by waste, the several talus slopes will merge, and we shall have a "graded slope." Graded slopes may also arise without the intervention of successive cliffs, as seen in the rubbish slopes of Pike's Peak above the timber line (Fig. 12).

45. **Alluvial cones.**—If a torrent or relatively swift stream discharges into an open valley or upon a plain, it will build

FIG. 25.—Alluvial cone, Visp Valley, Switzerland. Photograph by the author.

at the mouth of its gorge a fan-shaped structure to which the above name has been given. It will be but the segment of a cone, having its apex up the torrent valley and its margin extending more or less widely on the plane surface below. The deposit is due to the loss of velocity suffered by the stream as it emerges on open ground. The conical form is due to the dropping at its head of the coarsest and most abundant materials, and to the frequent shifting of the stream's course. Especially in powerful floods does the stream swing from one side around to the other, building up in irregular succession different parts of the cone. If the loss of velocity be very great, the deposit will be abrupt and the cone steep. If the change be moderate, the deposit will be gradual and the cone broad, gently sloping, and fanlike. Sometimes a stream cuts a deep channel through the cone, and builds a new one at a lower level, and partly between the dismembered parts of the older cone. The cone may form a barrier extending across the main valley, making a lake above, or may be built into a lake occupying the valley, turning a single lake into two, as at Interlaken. In the cases last described the cone, or its lower part, forms also a delta. In some mountain regions alluvial cones attain a height of 1,000 to 2,000 feet, and an extent of several miles. Davis cites the fan or alluvial cone of the Mercer River, which issues from the Sierra Nevada upon the great valley of California, and has built a fan of 40 miles radius.

46. **Flood plains.**—As we cross an ordinary open valley, we come, at the foot of the slope, or valley wall, upon a level tract of land, wide or narrow, on one or both sides of the stream. It is mostly composed of fine soil at the surface, though if we dig down we may encounter sand, gravel, and coarse stones. It is commonly arable, though subject to floods in the spring, or at other times when the channel is too small to hold the supply of water from the higher grounds. In the upper, torrential part of a river the flood plain does not appear, or is rough and composed of such stones and bowlders as the stream, with diminished velocity, leaves upon its banks. Flood waters carry much fine matter gathered from the slopes lying within the basin of the stream. As the waters spread over the meadows they lose most of their velocity and drop a sheet of silt upon the surface, thus raising it a little higher, and making a yearly

FIG. 26.—Flood plain and well-matured meander of small stream, Ray Brook, Adirondack region.
(Copyright by S. R. STODDARD, Glens Falls, N. Y.)

or more frequent contribution to its fertility. Emerson refers to the farmers who

> "Thank the spring flood for its fertile slime,"

and the Nile and many other illustrations will come to the mind of the student. The flood grounds of the Genesee in western New York are in some places nearly two miles wide. The Thames, though a small river, has so widened its valley in the soft rocks above Oxford as to have extensive flood plains. Those of the lower Mississippi are many miles in width. The Connecticut above Springfield, the Mohawk at Utica, the Susquehanna at Williamsport, and the middle Rhine are further illustrations.

The course of a stream through its flood grounds is unstable. Slight obstacles or inequalities in the resistance of its banks are enough to generate strong curves and propagate them down the valley. Such curves are called meanders, from the classic river of Asia Minor which illustrates this behavior of streams. On the convex side of such a bend the river cuts away its banks, and a bluff with caving turf and denuded roots is found. Trees of considerable size are undermined and felled in this manner. On the concave side of the bend deposit goes on, and a growing shingle beach slopes gently to the water. The sinuosity thus increases until sections of the stream are made up of a series of oxbows. The neck of one or more of these bows may become so narrow that in time of flood the river cuts its way across and leaves the oxbow at one side. The track of the steamboats on the Mississippi has been shortened 18 miles by a single cut-off. The riverward ends of the oxbow silt up, being at the point where moving water comes in contact with still water and drops some of its load. Thus a lagoon is formed. A subsequent change of course by the river may leave the lagoon at some distance, or, in a large valley, many miles inland. The maps issued by the Mississippi River Commission give many examples

FIG. 27.—Meander curve; gravel slope on the inside; under-cut bank on the outside; Calamity Brook, Adirondacks.
(Copyright, 1888, by S. R. STODDARD, Glens Falls, N. Y.)

of such phenomena. Mark Twain's accounts of the instability of the Mississippi may be read with great profit in this connection.*

Portions of a river may be diverted to several minor channels upon a flood plain of smooth surface. Thus the road leading westward out of Oxford crosses the several branches of the Thames by six bridges. The extent of such windings may be seen in the fact that the distance from the mouth of the Ohio to the Gulf of Mexico is 500 miles, while the course of the river covers 1,080 miles.

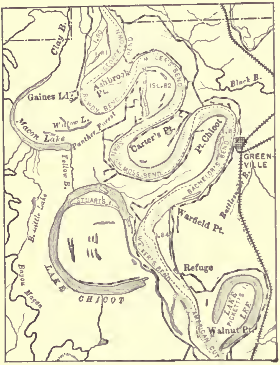


Fig. 28.—Meanders of the Mississippi, with cut off lakes.

The economic significance of flood plains is very great. Fourteen per cent of the arable soil in the Eastern United States is estimated by McGee to be of this alluvial nature, and 25 to 30 per cent of our population reside upon flood plains. Protection against disaster by floods is therefore important, and it is to be obtained by avoidance of the lowest grounds for building, where practicable, by substantial construction, and by dikes or levees. Within recent years the swollen Ohio has done much damage in the lower parts of Cincinnati. The Rhone has been known to rise $11\frac{1}{2}$ feet at Lyons, and the Seine 20 feet at Paris. In the autumn of last year (1899) the most destructive

* Life on the Mississippi.

floods since 1813 devastated the valleys of the Isar and other streams of Bavaria. The great floods of the Ganges and the Nile are well known. The most important flood problem in the United States is that of the lower Mississippi, where vast areas are sometimes flooded, and protection becomes a question of national interest.

47. **Natural levees.** — When a river overflows its immediate banks the course of the water is checked, both because it becomes shallow and because it encounters the trees and shrubs that flourish in such places. By reason of the loss of velocity, much of the load is at once cast down, leaving a thinner mantle of fine silt to be spread over the greater part of the flood plain on either hand. In this manner long lines of embankment are formed next the stream, from which the land slopes gently back to the valley sides, which in the case of a great river like the Mississippi may be several miles away. In more moderate floods these natural levees may be seen between the main channel and the back water of the meadows and fields. This phenomenon, according to Lyell,

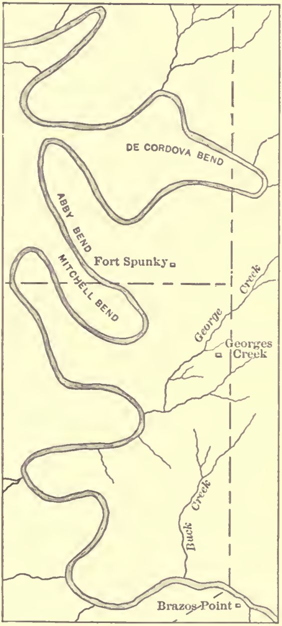



FIG. 29.—Meanders of Brazos River near Granbury, Texas.

appears for long distances on the Nile in the time of the annual flood.

A river of moderate flow carrying a full load will also build up the bottom of its channel as well as its banks, and thus may flow in an elevated trench of its own making. The Po is a notable illustration.

48. **Terraces.**—In open valleys, or along the "valley track" of rivers, platforms are often found rising like stairs upon the slope. They are of variable width, and although commonly horizontal to the eye will be found to descend gently with the stream. Each platform may be a few or many feet high, and the passage from one up to the next may be by a gentle or steep incline. They may appear in pairs on opposite sides of the valley, or otherwise. In material and appearance they are like flood plains, and they commonly are the remnants of old flood plains which have been abandoned by the river as it has deepened its valley. Each higher platform or terrace is in this case older than the one below it. In course of time the present flood plain, whose surface is raised slightly after every inundation, will be abandoned by the river if the latter be somewhat swift and still eroding its bed. Thus another terrace or pair of terraces will be added to the series and a new flood plain formed at a lower level. The interval between opposite terraces is wider as we ascend, and the distance between the upper ones may be many times the width of the stream. It must not be thought that the stream was necessarily wider when anciently flowing at the higher level. As it abandons each flood plain, the river not only deepens, but widens its track by the meandering habit already described, thus continually encroaching upon the riverward borders of the level it has left. Hence the terraces may be but a fraction of the original flood plain. Such encroachment often accounts for the absence of a terrace from one side of the valley when it is present on the other.

Terraces may consist of shelves of the bed rock of the region, over which the river has spread a mantle of gravel or silt, or they may be of unconsolidated land waste throughout. The difference depends upon the history of the valley. In the latter case we must think of a spacious valley previously excavated in the rocks and afterward filled with waste. The stream attacks this waste and carves the terraces as already described. Most valleys in the northern United States were once deeper than now, but during the Glacial period, when rock destruction was rapid, became


FIG. 30.—Cross section of valley with filling and subsequent terracing. *a a*, bed rocks; *b b*, upper, older terraces; *c c*, lower, newer terraces; *d*, low-water level of the river.—After SHALER.

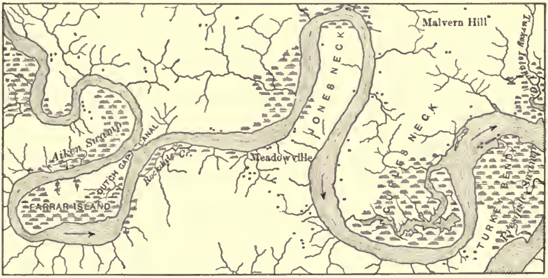



FIG. 31.—Meanders of the James River above the entrance of Appomattox River.

filled sometimes to a depth of several hundred feet. Since that time the streams have been cutting away this material, leaving parts of it as terraces. Russell cites the case of Snake River, the largest branch of the Columbia. A cañon

4,000 feet deep in some parts has been excavated, and was filled to a depth of 360 feet during the Glacial time with rubbish worn from the high grounds of Idaho. After the ice melted away the river, no longer overloaded, turned from deposition to excavation, carrying away most of the loose glacial material, and cutting into the rock below. The Merrimac and Connecticut valleys supply more familiar illustrations of such terraces.

The platforms here described are called alluvial terraces, because due directly to river action. It will be well at this point to note certain terraces of other origin which might be mistaken for them. Thus we have glacial terraces formed in valleys in the presence of waning glaciers, and terraces of differential erosion, due to the outstanding on a hillside of horizontal layers of harder rock. These may better be called benches. Structures resembling river terraces may be formed on the shores of lakes and seas, as will be explained in later chapters. If a valley be flooded by a lake or inflow of the sea, the streams which enter it will build deltas, and on the removal of the water by evaporation or emergence of the land, these deltas may resemble river terraces along parts of the valley. Such delta terraces are common in the Hudson-Champlain and Great Salt Lake valleys.

49. **Deltas.**—A delta is an accumulation of land waste at the mouth of a stream, on the border of a lake or the ocean. Its surface is partly a land area and partly submerged. The name was anciently taken from the subaërial part, because the Greeks saw that these deposits at the mouth of the Nile had the form of their letter delta ($\Delta$). They did not take account of the outer fringe which lies beneath the Mediterranean. Deltas are due to the loss of velocity which a stream sustains upon entering a body of water. Its load is laid down, the coarser fragments at once, and the fine particles after traveling some distance from land. In the case of marine waters, deposition is greatly hastened by the presence of salt in solution.

As regards deposition, Russell has made a useful distinction between the deltas of high and low grade streams. If a stream of large velocity enters a body of water, the load is at once dropped and an embankment is thrown out whose surface is slightly beneath the surface of the water,

FIG. 32.—Section of a delta, showing inclined beds made in forward growth, with nearly horizontal beds above.—After GILBERT.

and whose margin descends at a considerable angle to the bottom. A low-grade stream entering the sea after a long lowland course, like the Mississippi, Nile, or Ganges, carries nothing but fine sediment, loses its velocity very gradually, and hence builds beneath the water a gently sloping plane or fan, all of whose beds depart but little from a horizontal position.

We may make a similar distinction between the land portions of deltas. If a high-grade stream passes directly from its torrent valley into a body of water, its delta will be a partially submerged alluvial cone. Suppose, however, that a long valley track intervenes. We may regard the alluvial cones at its head or along its course as merging into its flood plains, and these in turn as passing into the delta. The delta begins at the point where the alluvial grounds have obviously been reclaimed from the water body. Likewise the natural levees continue into the delta area, the instability of the stream increases, and branches are given off to find the sea or lake by independent mouths. Such branches have been well called distributaries, and they accentuate the triangular form of the landward portion of the delta.

Deltas may be instructively observed as formed by rills in transient pools. After the water has soaked away, the radiating shallow channels on the surface, the lobate points

Fig. 33.—Delta built into a lake.

of discharge, the frontal slope, and the fringe of finer mud appear. Deltas of considerable size were thus formed in temporary lakes of Glacial time, and may now be studied to great advantage. The student should seek for deltas at the heads and along the borders of lakes. Ithaca and Watkins are built upon deltas at the head of Cayuga and Seneca Lakes, upon whose borders farther north numerous points are found, triangular areas of upland rubbish, now used for summer homes. Several streams may enter a mountain lake, their deltas grow rapidly, in time meet one another, and the area of the lake becomes a meadow. In large lakes this process would require a long period, even with rapid formation of deltas. Thus Lake Geneva is now 45 miles long. The Rhone river, muddy with the waste of Alpine glaciers and torrents, enters it on the east, and has built a delta 20 miles long, the last mile of which has been made since Roman days.

Rivers entering the sea do not commonly form deltas if the tide is strong. The Ganges is an exception, making a stupendous deposit in the face of powerful tides. This is no doubt due to its great volume, and to the mass of waste which it brings down from the highest mountains of the world. Also, if the land has been submerged, and the rivers enter a tidal sea through deep channels, the river deposits can not withstand the inrush of the tides. The Mississippi, the Nile, the Rhone, the Po, and the Rhine form deltas in regions of imperceptible or moderate tides. That the Rhine builds a great delta, and the Thames enters the sea by an estuary, is probably due to the excessive supply of waste which the Rhine receives from its high sources, while the Thames rises in an area of slight elevation, drains a small area, and pursues a short course to the sea.

We may now briefly review the extent and rate of growth of some of the great deltas. The delta of the Mississippi River is counted to begin with its first distributary south of the Red River, and its area is somewhat more than 12,000 square miles. Borings show that the alluvium of the delta is more than 1,000 feet deep near New Orleans. The delta of the Yukon has a length of 100 miles, and a seaward margin of 70 miles.

The seaward growth of the Low Countries is due to the building of great deltas by the Rhine and the Elbe, marking a transfer of the material of the Alps to the shallow seas of the north. The ancient records of the presence of civilized man on the shores of the Mediterranean make the

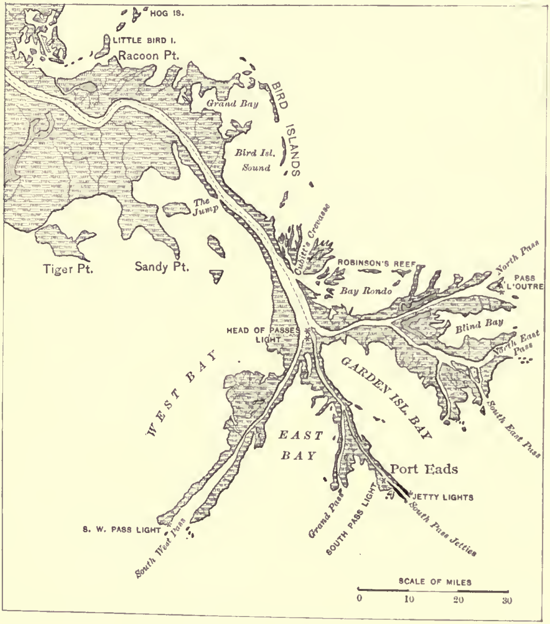



FIG. 34.—Delta of the Mississippi River.

deltas of this region especially instructive. The Rhone delta has grown 13 miles since the beginning of the Christian era. The classic port of Adria is now 20 miles inland, and the coast for 100 miles, from Trieste to Ravenna, has in the same period extended seaward from 2 to 20 miles.

50. **Estuary deposits.**—The wide mouths or lower sections of tidal rivers are called estuaries. There is in them a conflict between the outflowing fresh waters and the inrushing tide. At low tide, or in seasons of powerful floods, the river may have the advantage, pushing its waters and load of waste seaward. At other times the land waste is thrust back, and marine muds from adjacent sea bottoms are carried more or less up the channel. Such channels, deep enough to admit the sea, are commonly due to a former uplift of the land and the creasing of the coast region with land valleys during the period of emergence. Subsequent sinking of the land would "drown" the lower parts of the rivers. The deposits of an estuary tend to be cross-bedded and tumultuous, owing to the irregularity and conflict of currents. They may be in part coarse, if the streams head in a glacial or mountain region, and soon pass into the estuary. Some deposits are, however, of fine mud, much shifted and finely ground, moved up and down at intervals for a long time, before escaping into the sea. The fine ooze off the piers of the North River and the muds of the Thames at London afford illustrations. Nearly all the rivers of our Atlantic coast enter the sea through estuaries. Such are the Hudson, the Delaware, the Susquehanna, and the Potomac. The Amazon and La Plata are in the same class, and the greater rivers of England owe their commercial importance to this feature.

51. **Bars.**—These are closely related to estuarine deposits. Where the waters of a river are checked by the inward impulse of the tide, sediments are deposited, making shoals or islands. These constitute an inner bar. Thus in the Hudson River, the rise of the tide is noted as far as Albany and Troy. For some miles below, sediments accumulate rapidly, being checked after their swift descent from the uplands, and much dredging is needed to keep

the channel open for steamships. An inner bar may form at any point where velocity is diminished and much sediment is deposited. Outside of the mouth of the rivers in the margin of the sea bars are often formed. These are extended by currents moving alongshore, and may front much of a coast line, as is the case with New Jersey and the Carolinas. It is recorded that the apostle Paul sailed up the Cestra to Perga in southern Asia Minor. This would now be impossible, because the mouth of the stream is blockaded by an outer bar formed since the first century A. D.

52. **Variable constitution and structure of rocks.**—A river and its branches sinking their channels in rocks of different degrees of hardness and in beds of varying position undergo important changes of direction or relation, as do different rivers or systems in relation to each other. Some account of these changes will be given in the section on Physiographical Geology. It is, however, necessary at this point to study the origin of—

53. **Waterfalls and rapids.**—If a stream flows from harder upon softer beds, the latter will be cut away quickly and a rapid will result. Rivers thrown out of their ancient course by glacial accumulations often encounter masses of hard rock in sinking their new channel. They cut away the loose drift below and plunge swiftly over the unyielding barrier. The water power of Lowell, Mass., Pawtucket, R. I., or of Waterbury, Conn., results from such changes. The rivers of the Atlantic slope south of New York flow from hard older rocks upon soft newer rocks, and form thus a series of rapids and falls, at what is called the Fall Line, on which Trenton, Richmond, Raleigh, and other cities have grown up. Bowlders and coarse rubbish brought into the channel of a trunk stream by the torrential current of a tributary may form a barrier and occasion rapids.

Waterfalls are often formed by the recession of horizontal beds of unequal power of resistance. If a hard layer

Fig. 35.—Succession of waterfalls over horizontal beds of limestone, Trenton Falls, N. Y.

lies over a soft bed, the latter is cut and weathered away more rapidly, leaving the former as a projecting shelf, over which the water plunges. The blows of the water and the continued moisture break up the soft under rocks, while portions of the hard cap fall down from time to time as the support is removed. Illustrations of this process on a small scale may be seen in numberless ravines. Niagara is formed on the same principle. When the river began to take its present course, it found a high bluff known as the Niagara Escarpment, crossing its course toward Lake Ontario. In this region a mass of hard limestone overlies soft shales. In the manner already described these rocks have been cut away and the falls have moved southward 7 miles, leaving a gorge of that length. With this brief reference to the principle on which Niagara was formed, we defer the fuller study of its history to the chapter on the Glacial Period. The Falls of the Genesee at Rochester and Portage are formed thus, as also are the Falls of St. Anthony at Minneapolis. Shoshone Falls in Idaho have a like origin, though the beds in this case are lavas of extinct volcanoes.

The presence of vertical joints facilitates the formation of waterfalls in this manner, and small falls are often formed, due to this cause, when there is no apparent difference in the hardness of the upper and lower beds. Dikes of hard rock may cross the track of a river and cause waterfalls. Such cases are found in the Cascade region. The recession would here be limited to the thickness of the dike. When this is worn away a rapid will ensue, and finally a well-graded stream bed.

A cañon, rapidly or effectively deepened by stream action or formerly existing glaciers, may receive feeble tributary streams which are unable to sink their channels, and which therefore plunge over precipices of great height. Such are some of the "bridal veil" falls as in the Yosemite, the slender thread of water breaking into foam in its long descent. Numerous splendid examples are also found in the Alps.

54. **Changes due to climate.**—The Mississippi River has its sources in regions of varying temperature and rainfall, and is therefore fairly constant in its flow in different parts of the year, with now and then an exceptional flood. The Nile, however, rising in a tropical region, is much affected by the rainy season, and is subject to a periodical flood. Rivers may flow copiously from mountains, as in the western United States, but in entering more arid districts, in western Nebraska and Kansas, lose by evaporation and soakage, until the stream bed is left dry or with but scattered pools, during much of the year. In a similar manner the Abana and Pharpar, "rivers of Damascus," rise in the copious springs of Anti-Lebanon, and lose themselves in the desert east of the city whose life and beauty they create.

55. **Scenic and economic significance of rivers.**—Such considerations belong especially to the domain of physical geography, but here demand brief attention. In opening up the continents to man, rivers and their valleys have always been the avenues of discovery and settlement. Here first forests are cleared, roads built, crops planted, and cities founded. With few exceptions inland cities stand where rivers have conferred upon early settlers some special advantage. Nearly all available water power is due to changes in ancient streams, by which rapids and waterfalls have been formed. A multitude of cases could be cited from New England and many northern regions. Most important engineering problems and public works have to do with the navigation of rivers and the averting of floods. The usefulness of rivers is dependent upon the preservation of forests, and the Old World is promptly followed by the New in attention to this branch of practical science. The beauty of rivers is a theme for every lover of Nature, and opens endless fields for the higher appreciation of the world in which we live.

## CHAPTER IV

### UNDERGROUND WATERS

56. **Water in all rocks.**—The mineral constituents of rocks are not so closely aggregated as to prevent the admission of water. According as the rock has a close or open texture it will admit water in small or large amounts. Water may circulate with more or less freedom in rocks that lie above the sea level. Wherever soluble minerals, like rock salt, are undisturbed, it is evident that there has been little movement of subterranean waters. In compact rocks, or in those lying below sea level, the water contained may be that of original deposition—that is, it was involved with the sediments forming the rock as they were laid down in ancient seas. Hence such water is often found to contain salt. The more ancient, compact, crystalline rocks contain about 0.06 per cent of water. The ordinary sedimentary rocks average 2.05 per cent, though the amount is very variable. Gravels, sands, and clays may contain as much as 10 per cent. Dana estimates that there is water enough in the underlying rocks of the earth's crust to make a layer 1,300 feet deep over the continents. This is sufficient to produce most important chemical and mechanical effects, to which we now turn.

57. **Oxidation.**—This effect of water has already been considered under Weathering (see § 14); but reference was there had only to superficial rocks and soils. It is evident that along porous beds of rock which are inclined to the surface, as well as through fissures, water may descend to

great distances and aid in producing decay. Especially is this true in regions of recent lavas where much heat remains.

58. **Solution and cementation.**—Solution has also been noticed as a superficial process. This may go on to a depth of some thousands of feet. We have seen that surface water carries down with it various solvent acids. By their operation nearly all minerals, in small or large measure, are eaten away, and the dissolved matter is redeposited at lower levels. To this process is largely due the consolidation of rocks. Muds are turned into shales, sands become sandstones, and gravels are bound into conglomerates. Certain beds or pockets of glacial sands are often changed into resistant rock, while the adjacent masses can be still removed with a shovel. The more common cement is carbonate of lime, but iron, silica, and other substances act in the same manner. The most striking, though not the most important, effect of solvent water is in the excavation of caverns. As the phenomena of caverns involve several processes, both chemical and mechanical, constructive and destructive, they are treated at a later point in this chapter.

59. **Deposition in pockets and fissures.**—Any such openings are likely to be filled by means of descending water, redepositing matter from solution. This process is akin to the last described. As it is also one mode of vein-making, it will be noticed again in Part II. Here, as so often, a dynamic process leads to a definite form or structure. The two belong together, and are given separate treatment only as a matter of convenience.

60. **Mechanical erosion by underground waters.**—When a channel large enough to allow the free movement of water has in any manner been formed below the surface, streams may gather their abrasive tools, and carry on destructive work as effectively as if flowing in the open air. It is clear that such work can only be done above the level of the sea, or above the horizon of the surface drainage to which the

subterranean stream is tributary. We shall observe this process again in our study of caverns.

61. **Landslides.**—We can make no hard-and-fast distinction between the creeps described under Weathering and the more massive and deep-seated movements to which we now refer. The latter may occur in several ways. If a mass of soil or coarser *débris* be insecurely poised, as on a steep slope, and it becomes water-soaked, the friction that held the particles together is diminished, and the entire

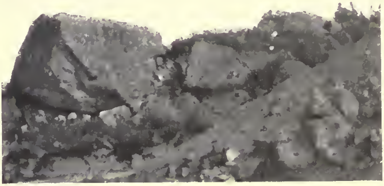


Fig. 36.—*Débris* of landslide of 1806, Goldau, Switzerland. Photograph by the author.

mass may push downward in a precipitate and confused way, forming an irregular group of knolls and hills at the bottom. Within the memory of white settlers, 17 acres of land thus slid from the steep western slope of the Genesee valley into the Gardeau Flats below Portage. If beds of rock incline with the slope of hill or mountain, under-beds, as of clay, may become moistened with percolating water, and serve as a lubricant on which the overlying masses slip down into the valley. Similarly, water passing through porous layers may carry out much matter in solution, and bring down the parts above by undermining. If steep cliffs are undercut by rivers or wave action, large portions may readily fall off, especially if the rocks be vertically jointed. Thus rock falls of tremendous proportions occur.

It is evident that the sides of valleys, particularly among high mountains, and the steep shores of lakes and oceans, are the theaters of such movements. In addition to the case above given, Dana cites a destructive earth slide occurring in the White Mountains in 1826, and Davis describes a great slide in the upper valley of the Ganges, in which, in three days, 800,000,000 tons of rock fell, leaving a cliff thousands of feet high as a scar on the mountain slope, and throwing a barrier 1,000 feet high across the valley. The bursting of the lake which thus formed was foreseen, and the immense flood that followed was not attended with loss of life. Destructive slides of vast extent have occurred among the Alps, sometimes destroying entire villages. Similar catastrophes have no doubt happened in great numbers before man lived on the earth. Moderate slides and falls are constantly occurring in all regions of rugged relief, so that this form of geological activity assumes high importance in the history of the earth. Further reference should briefly be made to landslides on seashores. Thus the English geologists have given many records of such "founders" on the coast of Devon and Dorset in south England. The rocks dip toward the sea, and clays are covered by firmer strata, as above described. Twenty-two acres of land were involved in one of these movements. Slides of small proportions, but of serious consequences, often occur along railway cuttings whose angle of slope is too great for security.

62. **Springs.**—These are formed by underground waters outpouring at the surface, and arise in several ways. Water sinking through soils and gravels may encounter a surface of the hard rock down which it flows to escape at some lower point, as the base of a hill. Water entering porous or jointed rocks may sink until it reaches a less porous bed, along which it passes to some point of outcrop. This process is facilitated if the beds be tilted at a considerable angle, and the waters of the spring may boil up vigorously,

because of the hydraulic pressure behind and above. Hence the abundance and strong flow of springs in mountain regions, where dislocations permit free entrance of surface waters, and sloping beds favor their outflow at lower levels. The water of springs is commonly cool and clear, because of its passage through regions little affected by the sun's heat, and because slowly moving underground streams can carry little rocky material in suspension. Some springs attain great volume. In the Nittany Valley at Bellefonte, Pa., a spring rises whose flow is about 14,000 gallons per minute. It is a region of dislocations, and the limestones which form the uneven floor of the great valley have become cavernous, receiving the surface waters, to emit them here and there in powerful springs. Silver Spring in Florida, at the head of the Ocklawaha River, is said by Le Conte to send forth such abundant waters that small steamers ascend the river and enter the pool of the spring. Another illustration is found at the base of Mount Hermon, in the great spring which supplies the head waters of the Jordan. If the structure of the underlying beds favors it, fresh water may flow for some distance under the sea, and rise in the form of springs through the shallow marginal waters. In a similar manner lakes are often fed by streams rising from the bottom.

63. **Mineral springs.**—All ground water dissolves minerals, and might strictly be called mineral water. But we reserve the term for waters which have a considerable quantity of dissolved mineral matters, particularly of such as give them medicinal value. It is plain that the character of the water will depend on the chemical constituents of the rocks through which it has passed. Thus some spring waters abound in sulphur, in iron, and in various compounds of sodium, potassium, calcium, and magnesium. Some famous springs are determined by fractures or dislocations, permitting free rise of the waters. Such are those of Saratoga, rising along the line of a fault, which is marked

by a shallow valley running north and south through the town. A publication of the United States Survey reports about 10,000 mineral springs in this country, and the list is no doubt very incomplete.

64. **Thermal springs.**—Spring water may not feel warm to the hand, but receives the above designation if it have a higher temperature than that of the region in which it flows. If it descends to deep levels and returns, it may be warmed by the remaining heat of the earth's interior. Frequently, however, waters are heated by contact with buried lavas, which, though relatively near the surface, have not yet cooled. Under this head belong geysers, which, however, will be treated in the chapter on Volcanic Action. Among the best-known thermal waters in the United States are those of Hot Springs, Ark., and many springs in the Yellowstone Park. Others are at Glenwood, Col., where a number of currents of very hot water boil up in and near the channel of the Grand River. Accounts of the Comstock mine in Nevada vividly describe the difficulties entailed upon the miners by the scalding waters of the lower levels. There is a great hot spring at Bath, England, occasioning a sanitary resort since Roman times. The temperature ranges from 104° to 120° F., and the discharge is 385,000 gallons daily. The depth of the sources has been computed at 3,500 feet. Owing to the greater solvent powers of heated water such springs carry much mineral matter.

65. **Deposits from springs.**—As water emerges at the surface it loses heat, or is relieved from pressure, and consequently its power to retain minerals in solution is diminished, and deposition takes place about the spring and along the stream which flows from it. Very commonly these deposits are of lime carbonate dissolved from the limestones traversed by the flow. It forms a porous incrustation, often coating twigs, leaves, and mosses, thus preserving their forms. Such a deposit is called calcareous tufa, or, if concretionary, travertine, and is often seen about the base

of limestone hills. Accumulations of one foot in thickness in four months are reported from Tuscany, now forming a hill 250 feet in height. Springs may form a brownish deposit of iron, and more rarely silica, or siliceous sinter, as it is called, is laid down. This happens only in rare conditions under which the usually insoluble silica can be affected. Such deposits of importance are found in the Yellowstone Park, in New Zealand, and in Iceland—all geyser regions. In the first of these localities the deposit is largely due to lowly organisms (algæ), which secrete silica from the waters.

66. **Wells.**—Ground water is formed at varying horizons, according to the nature of the soil and hard rocks, which thus determine the necessary depth. In sandy soils an abundant flow is often found but a few feet below the surface. Such water is quite sure to be contaminated and unfit for use, if in a town or closely settled region. Drainage from the stockyard often defiles the wells about farmers' dwellings. The surface of the ground may slope in one direction, while the dip of the layers of rock or sand is such as to carry sewage directly into wells whose opening may be at a higher point. Well water in towns, no matter how clear in appearance, can safely be counted dangerous. Only expert analysis should be trusted, and the test must be often repeated. If a well is sunk below a bed of fine clay, and securely cased down to the clay, its waters are likely to be pure. The contamination of surface and subterranean waters in populous regions leads more and more to wise care and large expenditure for a trustworthy supply. We may cite in illustration the large attention given to water supply by the State of New Jersey, especially for the dense populations near New York; also the care bestowed upon the Croton watershed, and the conducting of Lake Skaneateles waters at great expense to the city of Syracuse, and of the Thirlmere waters to Manchester. Nor should we omit the growing recognition of the necessity of outside water supply in all villages of any size.

Artesian wells are so called from the province of Artois in France, where this method of obtaining water has long been used. In a true artesian well the water flows freely, or, if the pressure be sufficient, forms a jet or fountain. The conditions are: The existence of a slightly inclined and continuous porous stratum lying between compact or impervious strata above and below. The latter, which may


Fig. 37.—Ideal section illustrating the chief requisite conditions of artesian wells. *A*, a porous stratum; *B C*, impervious beds below and above *A*, acting as confining strata; *F*, the height of the water level in the porous bed *A*, or, in other words, the height of the reservoir or fountain head; *D E*, flowing wells springing from the porous water-filled bed *A*.—After Chamberlin.

be of clay or any fine-grained rock, serve to confine the water. The porous bed, as of sand or sandstone, serves to conduct the water from the surface and also as a reservoir. If a boring be made from the surface in the direction of the "dip," by the ordinary principle of hydraulic pressure, a flowing well is produced. The inclination of the beds is usually slight, but a few feet to the mile, and the well is often some scores or hundreds of miles from the point where the waters enter the earth. It is evident that a region of much-broken or dislocated rocks is unfavorable for artesian wells. Such sources of water supply are important along the Atlantic coast, as in southern New Jersey. There are many artesian wells in the valley of the Mississippi and in the region of the Great Lakes. Artesian waters have long been used in Chicago, the wells being supplied from the gently inclining rocks of southern Wisconsin. Other wells are found at Louisville, St. Louis, and New Orleans. They are important on the Great Plains, in Dakota, Nebraska, and Colorado. Utah and California are other localities, the waters serving for domestic use and for irrigation.

## Caverns

67. **Classes of caverns.**—Open spaces carried to greater or less distance within the rocks may be produced in several ways. Thus we have sea caves hewn out by the waves. These are never of great size. Also along planes of dislocation when fissures are made and parts of the rocky crust of the earth move upon each other small cavernous openings may be formed. The outflow of lavas from a cooling crust sometimes gives origin to caves. But the great caves are always due to the circulation of waters beneath the earth's surface, and their mode of formation will now be described.

They are chiefly due to processes of solution and must therefore be made in rocks which yield to the attack of water and the acids which water carries. The only common rock of which this is true is limestone, and therefore it is in such rock that all great caverns are excavated.

68. **Conditions and mode of formation.**—For the making of great caverns it is essential that the limestone consist of massive, thick beds, comparatively free from alternating layers of sandstone or shale. Along the downward line

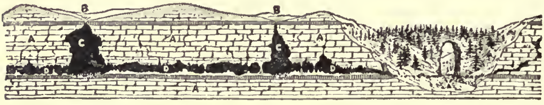



Fig. 38.—Diagram showing action of soil water in excavating caverns. *A A*, layers of limestone easily dissolved in soil water; *B B*, sink holes by which soil water enters the cave; *C C*, vertical shafts or domes; *D D*, horizontal galleries. At the right is a natural bridge, or remnant of a large cave.—After Shaler.

formed by the intersection of two joint planes the waters slowly find their way. They are laden with acids gathered from the air and from vegetation, and solution takes place, slowly forming what are termed sink holes. From these the process of solution works laterally along the planes of bedding, and often at several levels. Thus a region may become honeycombed with a network of vertical and horizontal passages. The entrance may be small and long undiscovered, and yet lead to extended tunnels and lofty chambers. The waters by which the work is effected find their way laterally to adjacent hillsides or mountain slopes and issue as springs or brooks to unite with the surface streams. It is evident that such movements can only take place above the drainage level of the region. At lower levels water could circulate but slightly, if at all. A cavern is limited in depth by the position of the local base level of erosion. After cavernous passages become large enough to permit the free flow of water, they may then be enlarged and deepened by mechanical erosion. Lakes, rapids, and waterfalls are also found in caverns. As the excavation progresses, the roofs of passages which lie near the surface are weakened and fall in. Thus some gorges originate, and wherever portions of the roof remain, the so-called natural bridges are formed, as the famous Natural Bridge of Virginia.

69. **Deposition in caverns.**—Erosion is not the only important process which takes place in subterranean chambers. Minerals, especially carbonate of lime, are dissolved by percolating waters and redeposited on the walls and floors. Thus at a point where water slowly drips from the roof of the cavern, pendant needlelike masses form, which are called stalactites. Sometimes they are broad and massive rather than round and slender, and they may attain great length and size. They steadily grow in length downward, and by accretion outward, in successive layers, so that a cross section is similar in general appearance to the cross section of a twig or tree. Not all of the material in solution is thus deposited, but some is carried by the dripping water to the floor of the cavern, forming irregular, knobby masses, called stalagmites. Sometimes the stalactite grows downward and becomes continuous with the

FIG. 39.—Remnant of underground stream channel, Natural Bridge, Va. Photograph by U. S. Geological Survey.

stalagmite. At some points the roof undergoes disintegration, and fine material and coarse fragments fall to the floor. These may be worked over or mingled with waste brought by streams from the surface. Not infrequently caves have been the refuge or home of animals and of primitive savages, and thus organic remains are added to the rest, even those of historic and civilized man being found in some countries. Thus the processes of destruction and accumulation go on underground in cavernous regions as variously as on the surface of the earth.

70. **Noteworthy caverns.**—One of the most famous caverns of the Old World is at Adelsberg in Austria. It consists of four great grottoes, in which an annual festival is said to have been held on Whitsunday. It was known in the middle ages, afterward fell out of mind, and was rediscovered in 1815. The Mammoth Cave of Kentucky is the best known of American caverns, having been extensively studied and carefully mapped. It was found in 1809 by a hunter who was pursuing a wounded animal. It is excavated in the subcarboniferous limestone, having its mouth in a ravine 600 feet above the sea. There are 150 miles of passages, with lakes, rivers, and a waterfall 250 feet in height. The extremity of the cave is several miles from the entrance. It has been estimated that there are in Kentucky 100,000 miles of subterranean channels sufficiently large to permit the passage of a man. Many "sinks" are found upon the surface, due to subsidence. Some of these sinks are occupied by small lakes. Luray Cavern, in the Shenandoah Valley, Virginia, was discovered by means of such a sink in 1878. It surpasses in the number, size, and brilliant coloring of its stalactites, of which 40,000 are said to be visible from a single point. Of these are the "Swords of the Titans," eight in number, 50 feet long, 3 to 8 feet wide, 1 to 2 feet thick and hollow. Their edges are thin, and they give off deep, resonant sounds when struck. Howe's Cave, in eastern New York, is a smaller but well-

Fig. 40.—Stalactites, Luray Cavern, Va. Photograph by James.

known limestone cavern, and Wind Cave is an important illustration of cave-making in South Dakota.

Cave-making is of much geological importance. We shall learn that during geological eras large bodies of limestone have not seldom been removed by erosion. A considerable proportion of such erosive work has always been subterranean. The peculiar environment which caverns afford for animal life, as in the case of fishes and insects, has produced changes of structure of high interest to the student of biology. Mythology and ancient history abound in references to caverns in relation to man, who, as in the narratives of the Hebrew Scriptures, used them as places of habitation, refuge, and of burial.

# CHAPTER V

## GLACIERS

71. **Definition.**—A glacier is a mass of ice flowing in a valley or overspreading a tract of country. The size, form, and behavior of glaciers depend upon local conditions and vary greatly. Valley glaciers are long or short, wide or narrow, rough or smooth, according to the form of the valley and the extent of the snow fields above it. Similarly ice sheets may spread out for short distances from mountains, as south of Mount St. Elias, or they may cover vast areas, as in Greenland. Likewise the rate of movement is variable, though always slow, and their geological efficiency is in many degrees and kinds. Agassiz, many years ago, well observed that the study of a single glacier was quite inadequate to the general understanding of the subject. Within the past decade the glaciers of Alaska and Greenland have yielded a great body of fresh facts, and the antarctic regions may prove to be even more instructive. Glaciers have been a most important factor in the history of the earth, and have an especial interest in most northern countries.

72. **Conditions and mode of formation.**—The conditions of glacial formation are three in number:

(1) Abundant snowfall. Such a region is found in the Alps, where the winds, laden with moisture from the warm Mediterranean region, discharge their load, or similarly on the southern shores of Alaska, where the evaporation from the Pacific Ocean supplies the water, and the cold of the

high mountains turns it into snow. Agassiz records 57½ feet of snow as falling in six months at the Grimsel, and 6½ feet in one night at St. Gothard.

(2) A sufficient degree of cold to preserve part of each winter's fall of snow. In most regions, at ordinary altitudes, a winter's snow disappears early in the following spring or summer. But if the summer is so short or cool that a moderate residue is annually retained, glaciers must result. It thus appears that intense cold is not essential to the formation of glaciers, but rather a suitable ratio between snowfall and temperature. Greenland is a great ice field, while the adjacent parts of the American continent are without glaciers. The same contrast holds between the glaciated southern slopes and unglaciated northern slopes of the Mount St. Elias range. Rank vegetation sometimes thrives and flowers bloom on the borders of glaciers. The student should at the outset emphasize this second principle of glacier formation.

(3) A somewhat extended high area in which the snows may be held and consolidated. This relates more especially to mountain glaciers. Isolated cones and steep mountain slopes may bear no glaciers, because the snows are readily dislodged and descend chiefly in the form of avalanches. But a deep gorge or broad shelf on the mountain side may retain snow enough to form a glacier. Especially is this true of high basins formed by several adjacent mountains. The snows descend on every hand by creeping movements or by avalanches, and form a common mass, out of which the glacier, or group of glaciers, takes its origin.

73. **The mode of formation of a glacier.**—It must be remembered that snow is only ice which has been formed in the upper air in small crystals of various shapes, and that snow appears white because light is freely admitted into innumerable spaces between the crystals. As the snows become massed together in a high mountain basin or on plains below, these crystals are broken, the spaces dis-

appear, and the snow assumes the form and color of solid ice. This process is a gradual one. The snow at first becomes granular, like the snow of early spring, and in this condition the French call it *névé* and the Germans term it *Firn*. Even the blue ice of the solid glacier may be broken up into irregular crystals of various size, to which the name glacier corn has been given. The glaciers will follow the lowest passes or valleys which lead out from the region of accumulation. If we ascend a glacier stream in the summer we shall first traverse a field of ice, whose surface is rapidly melting. Farther up we come to a portion of the glacier which is covered with the unmelted snows of the last winter. At the depth of a few inches or a few feet one may pierce to the solid ice. Still above are the steep slopes covered with the later snows. These may reach to the summit, or peaks and ridges on which no snow can lie may rise out of the snow fields. There is no sharp line at which the glacier ceases and the snow field begins. And the so-called snow line is most irregular. The amount of snowfall, the steepness of the slope, and the relation of the slope to the noonday sun, cause the line of perpetual snow to vary greatly even in adjoining regions.

## The Motion of Glaciers

A glacier is a geological agent chiefly by reason of its movements. These will now claim our attention. We shall consider the proofs, characteristics, nature, and results of glacier motion.

74. **Proofs.**—The movement of a glacier is not apparent to the eye. It appears like a stagnant mass of ice strewn with rocky rubbish and snow. In 1820 some Swiss guides were lost in a crevasse. In 1860 their remains were found at a distance down the valley. In 1827 a Swiss naturalist, Hugi, built a hut on the Unter-Aar Glacier. In 1841, according to Agassiz, the hut had moved 4,712 feet from its

original place. The movement had been at the rate of more than 300 feet per year. The advance of a glacier has sometimes destroyed villages in the valley below. These examples may be called earlier general proofs. We have also the later, exact measurements of Tyndall and others. Two stakes were planted in fixed positions on either side of the glacier, and others between them, in a direct line across the ice. Movements of these relative to those fixed at the ends would determine the fact of motion and its amount. The movement of six posts, set by Agassiz across the Unter-Aar Glacier, was as follows in one year:

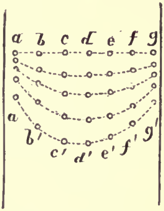


FIG. 41.—Stakes *a*, *b*, *c*, etc., show by successive positions the relative movement of middle and edges of glacier.

160, 225, 269, 245, 210, 125 feet.

It thus appears that the daily motion was from 4 to 9 inches per day. The wide glacial streams of Alaska and the Greenland coast move much more rapidly than this. Some Greenland glaciers move from 40 to 60 feet per day, and even a higher rate has been reported in a few cases.

75. **Characteristics of glacier motion.**—It has been found that in several respects the motion of a glacier is like that of a river. Thus the most rapid movement is in the middle portions. The sides of the ice stream are detained by the friction of the valley walls. The measurements given above show this as well as the following, given in inches per day:

5, 8, 10, 9, 9, 8, 6, 9, 7, 6 inches.

Here we have near the middle, a point of less motion, probably due to obstruction under the glacier. A glacier moves more rapidly at the top than at the bottom. The movement is also greater in summer than in winter, and more rapid during the day than in the night. Several broad glaciers may unite into a trunk stream, which is much narrower than the combined width of the tributary streams. The trunk glacier in this case must be deeper or must move more rapidly. Here the similarity to rivers is close, as, for example, to the whirlpool gorge of Niagara. The ice stream behaves much like a river in passing obstacles. The ice molds itself to the form of its channel as perfectly as water. The illustration of the winding Viesch Glacier (frontispiece) shows this. A rocky hummock in the track of the glacier will be overridden, if not too high, as the water of a torrent rises over a bowlder in its bed. If the obstruction rises through the glacier, the ice will flow up on the side of approach, and sink away from the lee or protected face.

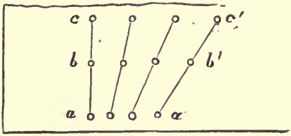


FIG. 42.—Stakes *a, b, c* show by successive positions the relative movement of upper and lower portions of glacier.

**76. Nature of glacier motion.**—Much has been written, but our knowledge is not definite. According to one of the chief theories, ice, brittle as it is, is slightly viscous, and hence will flow under pressure. It is urged, in illustration, that pitch, such as asphalt, will flow with sufficient time, but fractures under the hammer like any other brittle substance. The same would be true of a bar of molasses candy. Another theory is that, under great pressure above and from behind, the ice is minutely broken, and the par-


FIG. 43.—Converging and diverging flow of glacial ice between elevations.—After SHALER.

ticles united again by freezing, after undergoing a slight relative change of position. For other hypotheses the student is referred to larger works. A good account may be found in Le Conte's Elements of Geology.

77. **Results of glacier motion.**—Here we have certain elements of structure, erosion, and transportation.

Fig. 44.—Looking south across the Unter-Aar Glacier. Crevasses and medial moraine. Photograph by the author.

78. **Elements of structure due to motion.**—Most obvious of these are the crevasses due to unequal strain. Thus the glacier moves faster in the middle than toward the sides, and it is found that such strain forms fissures, running upward and inward from the sides. Others are formed when a glacier descends over a sharp slope in its bed, as in the

great ice fall of the Rhone Glacier. The hummocks and pinnacles thus formed are called seracs. There is also found a thin vein structure or banding of layers of white and blue ice, believed to be due to pressure. The appearance of stratification is sometimes seen, with dirt bands, due to successive deposits of snow with *débris*-covered surfaces; or sometimes the layers of rubbish are carried into the heart of the glacier from rocky obstructions, which are steadily eroded away.

79. **Erosion.**—The thickness of a glacier may be several hundred feet, or, in the case of ice sheets, several thousand feet. The movement of so heavy a mass of solid matter exerts a powerful rending force upon the rocks over which it passes. Materials whose cohesion has been lessened by weathering, and blocks due to bedding, joints, and cleavage

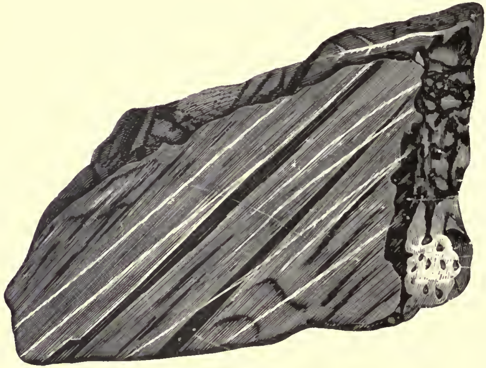


Fig. 45.—Glacial scorings.—After Agassiz.

are readily plucked from the bottom and sides of a valley. The lower parts of the ice stream are set with such masses, which serve as graving tools, and are rasped with great energy over the bed rocks beneath. By this means not only are rocks dislodged from below, but large quantities of fine rock flour are produced. The under rocks are scored and graven in a most characteristic manner. Such marks are known as glacial striæ, and such a surface is often said to be glaciated. The gravings may be fine, as if done by a delicate point, or coarse and rough, as when made by the pushing of a heavy and angular bowlder. Sometimes quite elaborate flutings and moldings are made in this manner. They are often to be found where soil and drift are stripped from the rock, as for quarrying. The more delicate markings are best taken by fine-grained rocks, such as many limestones. The striæ are useful, not only as proving glacial action, but because in general they show the direction of the ice movements. Rocky eminences rising in the track of the ice are smoothed down and carved into low, elongated ridges and swells, known as *roches moutonnées*, from their resemblance to the backs of a flock of sheep. It is evident that the stones pushed under the ice must be similarly scratched, and hence we find the glaciated pebble, a most characteristic product.*

80. **Transportation by glaciers.**—Glaciers which occupy valleys with steep sides, especially among high mountains, receive large contributions of rocky and earthy *débris* from above by the ordinary processes of weathering, by avalanches and landslips. It is evident that this material will share the motion of the glacier. Some of these fragments from time to time descend into the ice by means of crevasses and glacier mills. Other masses are carried into the heart of the ice from rocky heights that rise into the glacier, or by means of cross currents within the ice. Much rock is also taken into the lower portions of the ice, as already described. A glacier thus transports materials upon, within, and under its mass. Such material is technically called superglacial, englacial or intraglacial, and subglacial. Great ice sheets which cover the high grounds

* See Fig. 285.

of a region carry most of their rocky burden at or near the bottom. An interesting difference between transportation by a river and carriage by glaciers lies in the fact that the size of the stones carried by the glacier bears no relation to its velocity. The slow rate of travel should not be thought to destroy the importance of glacial transportation. The student should ever seek to enlarge his conception of the time which is available for the earth's history. There is abundant proof of the carriage of material for several hundred miles in North America and northern Europe. A fuller account of these facts belongs to the section on Historical Geology.

81. **Moraines.**—A moraine is an accumulation of rocky matter carried by the glacier, or deposited by it through

FIG. 46.—Looking up the left lateral moraine of the Tschingel Glacier, Switzerland. Photograph by the author.

melting. It might therefore with some reason be treated in the next section. But, as will be seen, certain kinds of moraines take form on the moving glacier. On the borders of a valley glacier stony rubbish gathers, both by plucking and by descent from cliffs. This material forms lateral moraines. It is in part borne by the glacier and in part banked against the valley sides. When the glacier melts away, the lateral moraine is left as a narrow ridge, often of sharp crest and steep slopes, straight or curved, according to the form of the valley.

When two glaciers unite in a trunk stream, the adjacent lateral moraines form a medial moraine, which is carried on the surface as a ridge of angular bowlders. Thus the medial moraine of the Unter-Aar Glacier is several miles long, often 100 feet high, and several hundred feet wide. If several glaciers unite into one stream, a number of medial moraines will appear, parallel to each other.

The most important and complex accumulations are made at the front or terminus of the glacier, and are called terminal moraines. Materials carried under or within the glacier must come to rest where the ice disappears by melting. In like manner materials which travel to the front as part of a lateral or medial moraine mingle with the terminal mass. Large frontal areas of the glacier may be hidden by such waste. When the glacier recedes by melting, the terminal moraine may appear as a crescentic ridge with its concave side up the valley, or it may be a hummocky and irregular assemblage of material occupying the valley for some distance. The latter is the case if the position of the front is subject to considerable oscillation. Especially in front of the ancient ice sheets are the moraines found to be broad and intricate belts of knolls and ridges, rather than narrow and well-defined lines of accumulation. A succession of pauses in the melting away of a glacier may give a succession of terminal moraines.

Wherever a glacier has disappeared by melting, the area is usually occupied by a sheet of rocky and earthy matter, known as the ground moraine. This has its chief importance in connection with the ancient ice sheets.

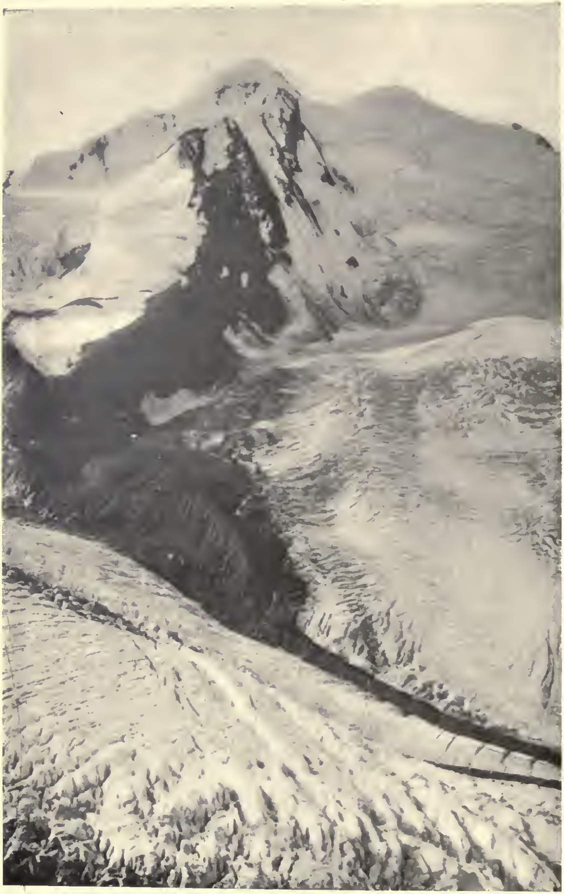


Fig. 47.—Alpine glacier; crevasses and formation of medial moraine.

**Material of moraines.**—The lateral and medial moraines consist chiefly of angular, unworn bowlders and smaller fragments. Terminal moraines, on the other hand, contain many rounded and worn masses, abraded under the ice or

FIG. 48.—Pool on glacier. Ice thinly covered with angular bowlders. Photograph by the author.

rolled in glacial waters. Much, and sometimes all, of a terminal moraine may consist of tough, clayey matter or rock flour, more or less set with stones.* Much water-worn and stratified matter, however, often belongs also to these terminal accumulations. These differences depend upon a great variety of special conditions.

## THE MELTING OF GLACIERS

82. Whenever the season permits melting takes place everywhere on the surface of a glacier, and to some extent

* Bowlder clay, or till. See p. 428.

within its mass and at its base. In the last case something is due to internal and basal friction. A number of characteristic phenomena thus arise. Rills, and sometimes small torrents, rush down the surface, usually to disappear in crevasses or well-like openings in the ice. This water reaches the bottom and forms the subglacial stream which issues from all glaciers, usually by a broad, low tunnel or arch. Thus the Aar River issues from the Unter-Aar Gla-

Fig. 49.—Aar River flowing from beneath the glacier. Photograph by the author.

cier, and the Rhone River from the Rhone Glacier. The subglacial stream, like an open-air torrent, is a powerful instrument of erosion. Its carrying work is even more conspicuous. Materials gathered under the ice or picked from the terminal moraine are spread out in stony alluvial areas in the valley below. Especially does the subglacial stream carry much rock flour, the product of glacial abrasion. So whitened by this means are some streams that their waters are called glacier milk. Two hundred and eighty tons of sand were found to have been discharged in one August day by the stream flowing from the Aar Glacier.

83. **Honeycombed surface and glacier tables.**—During summer days melting is very active, and the surface of a glacier may consist of innumerable small pinnacles and pits. Small pebbles lying on the surface absorb the heat, quicken the melting, and thus sink into the ice. On the other hand, large slabs or bowlders protect the ice beneath

Fig. 50.—Glacier table. Ice pedestal melting on south side, Unter-Aar Glacier. Photograph by the author.

from the heat, while the adjacent ice melts away, leaving the slabs mounted upon ice pedestals sometimes several feet in height. The south side of the pedestal will melt most rapidly, and the slab will incline in that direction, until at length it slides off and the process is repeated in its new position. One slab seen by the writer was elevated on two ice pillars, between which flowed a vigorous stream of water. The stream had found its way under the bowlder while the stone lay on the common level, and had sunk its channel while the sun lowered the surrounding ice.

84. **Ice pinnacles.**—A layer of sediment may gather in a pool on the glacier. The underlying ice is thus protected from the heat while the surrounding ice melts away. The

Fig. 51.—Ice pinnacles veneered with waste, Unter-Aar Glacier. Photograph by the author.

protected ice assumes at length the form of a sharp cone, covered with a very thin layer of sánd. In a cone several feet high and of sharp apex the ice may rise to within an inch of the top. It will be seen that the ice pinnacle is closely related to the glacier table.

85. **Glacier mills.**—A surface stream often discharges into a crevasse, causing it to widen at that point. If now the crevasse closes, a round or oval opening is left, receiving surface waters, which in turn may erode or melt the ice to form irregular or spiral pits descending profoundly into the glacier. Thus we have the glacier mill. A change in

the stream may leave the pit dry. Agassiz descended to a depth of 125 feet in one of these, to study the interior structure of the ice, whose banding and color could thus be seen to advantage.

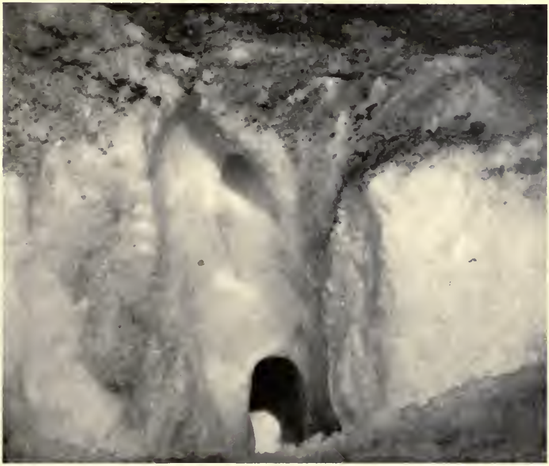


FIG. 52.—Abandoned glacier mill, Unter-Aar Glacier.
Photograph by the author.

## EXISTING GLACIERS

A full account of existing glaciers belongs to physical geography. We here review the subject briefly, giving the distribution of the great types of glacier. This will also aid in understanding ancient glaciation.

86. **Valley glaciers.**—These are well developed in Switzerland, where they are found to the number of many hundreds, are most often visited, and have for many years been carefully studied. The chief glacier regions of Switzerland are three: The vicinity of Mont Blanc, with the Mer de

Glace and other ice streams; about Zermatt, where several large glaciers stream down from the Monte Rosa chain to form the huge Gorner Glacier; and the Bernese Oberland. In the last we have among many others the Aletsch, the largest ice stream in Switzerland; the Grindelwald, reaching down within 3,000 feet of the sea level; and the Unter-Aar, made famous by the studies of Agassiz and others. There are many glaciers in the eastern Alps, in the Pyrenees and Caucasus, and in the mountain valleys of Norway. Considerable glaciers are found in the Himalayas, but of these little is known. Small valley glaciers occur in the high mountains of California, Oregon, and Washington, larger ones in the mountains of British America, and some of great size in southern Alaska, among them the celebrated Muir Glacier.

87. **Piedmont (foot of the mountain) glaciers.**—A single glacier of this type has been described by Russell, the Malaspina, extending from the foot of the Mount St. Elias range to the sea, 30 miles, and having a width of 70 miles. It is formed by several valley glaciers merging on the plain, and its stagnant border on the south is covered along a belt several miles wide with morainic soil and extensive forests. (See Fig. 54.)

88. **Ice sheets.**—These are of special geological interest, because they illustrate at the present day the conditions and size of the ancient ice fields. The best known of these sheets is in Greenland, whose entire interior to the extent of several hundred thousand square miles is mantled with ice, covering all elevations. It is comparatively smooth, and carries on its surface but a slight amount of rocky *débris*. From this ice field tongues or streams flow down the valleys which lead from the interior to the sea. The interior ice has been explored by Nordenskiöld, Nansen, and Peary, while the ice streams that enter the sea have been seen by many arctic explorers, and in recent years have been studied by Chamberlin and others. The Hum-

Fig. 53.—Greenland glacier entering the sea; three miles in width; shows crevasses and small icebergs.

boldt Glacier enters the sea with a width of 60 miles. A vast ice sheet, perhaps equal in extent to any that existed in the Ice age, covers the antarctic region. Little is

FIG. 54.—Vegetation on moraine-covered portion of the Malaspina Glacier, four miles from the front of the ice.

known of it, with exception of its steep seaward cliffs, along which vessels have sailed for several hundred miles. It offers a great field for glacial study.

89. **Icebergs.**—The mountain-like masses of ice which float in the Atlantic, and to some extent in other marine waters, have their origin in glacial streams. The front of the glacier is buoyed up as it enters water which is deeper

than its own thickness, and huge masses break loose and float away, bearing the waste which may rest on their surfaces or be frozen within their mass. They may be carried to distant latitudes by ocean currents before they disappear by melting and contribute their deposits to the sea bottom. Where the cliffs of a glacier front rise high above the marginal waters of a sea or lake small icebergs form by the "calving" off of crevassed masses, which fall into the water and float away. Thus Glacier Bay is often covered with small bergs from the front of the Muir Glacier. Icebergs and their deposits were of some importance in the Glacial period in the region of the Great Lakes.

90. **Avalanches.**—In all regions of high mountains avalanches have geological importance. On steep slopes above the snow line masses of old and new snow are often dislodged to descend with terrific force into the valleys. Trees lying in their path are destroyed, and avalanche tracks may often be seen running down the forest slopes in parallel or radiating lines. Well-defined avalanche tracks are found in the Rocky Mountains, as on the slopes about Silverton, Col. Avalanches sometimes occur among the White Mountains of New Hampshire. So numerous are the avalanche paths in the Alps that an elaborate official map of them has been prepared for publication. These tracks may readily be adopted by mountain torrents, and erosion thus be carried on indefinitely. Avalanche snows lying on the lower slopes are often thickly set with stones and rough bowlders brought from above, and the destruction of life and property by them is sometimes serious. Even the wind generated by the movement of a great avalanche may suffice to prostrate a forest. Similarly ice falls occur. From the so-called hanging glaciers, perched on lofty mountain shelves, masses crack off, forming a dense cloud of pulverized ice as they are crushed by their fall, or pouring as a torrent through narrow ravines in the lower mountain slopes.

# CHAPTER VI

## LAKES

91. **Definition.**—A lake is a body of surface waters, lying apart from the sea, usually above it, and detained by a natural barrier. Lakes occur wherever inclosed basins have in any manner been formed, if the bottom is sufficiently impervious, and if there be an adequate supply of water. They differ from the ocean in size, in the position of their surface, which is usually above, though rarely below, sea level; and in the character of their waters, which are commonly fresh, but in a few cases are more salt than the sea. They sustain a close relation to rivers, of which they may be considered as lobelike expansions. Thus the St. Lawrence River is more properly regarded as having its head waters in Minnesota and Canada, and as passing through the chain of the Great Lakes on its way to the sea. Lakes are comparatively short-lived features of the earth's surface. Many land surfaces have, however, been formed and destroyed or profoundly modified during the earth's history, and hence there must have been many generations of lakes. The basins are physiographic forms, and will therefore be more fully treated under that head (see Chapter XIV). This is the more necessary because they are often of highly composite origin, a variety of geological forces and structures combining to make them what they are. We are here only concerned with the geological work which lakes may be said to perform and for which they furnish the opportunity.

92. **Geological work of lakes.**—The chief movements of lake waters are waves produced by the winds. By their

Fig. 55.—Lake Ontario. South shore, half a mile east of Forest Lawn, looking west. Waves cutting a cliff in glacial drift, with floor of Medina sandstone. Photograph by H. L. Fairchild.

means erosion is accomplished upon shores and on shallow bottoms. In the case of small lakes the amount of such work is slight, but on large lakes the winds sweep powerfully, waves roll high, shore cliffs are formed, and much rock is broken up and distributed over the lake bottom. This work is similar to that of the ocean, and the student is referred to that subject for fuller treatment. Lake bottoms, like sea bottoms, are everywhere the recipients of fragmental materials brought from adjacent lands. Near the shore coarser fragments worn by waves or brought by streams are laid down. At the mouth of streams deltas are formed, precisely as in tideless seas, with the difference that streams of swift flow often enter lakes directly, their load is dropped suddenly, and the deltas afford highly inclined beds and frontal slopes. Beneath the deeper offshore waters of lakes, as well as seas, the finer sediments come to rest, and both shore- and deep-water deposits may contain the forms of plants and animals which once inhabited the waters, or whose remains have been drifted in by streams. In large lakes currents of importance may be generated by winds, and may be an efficient means of transportation, particularly for the redistribution of sediments alongshore. Lake-bottom deposits have afforded much instruction, because in some cases lakes have disappeared, leaving their varied shore lines, deltas, and bottoms perfectly exposed for study. Thus we have the Lakes Bonneville and Lahontan, and the glacial extensions of the Laurentian lakes (see Chapter XXV).

Lakes are also economically important, because they regulate the flow of river waters, serving as reservoirs by which the water that falls on the higher grounds is detained and sent on gradually to the sea, thus averting floods and modifying the conditions of vegetable life. They also modify the climate of surrounding regions by delaying or averting frosts, and by offering surfaces over which large evaporation and cloud formation take place.

Fig. 56.—Shoreward shove of materials by ice on the border of a lake. Iowa Geological Survey.

93. **Salt lakes.**—We have already seen that water which flows over, or within the rocks and soil, carries some mineral matter in solution. In the ordinary lake with constant inflow and outflow, this percentage of solid material does not increase. But if conditions arise in which there is no outflow either on or under the surface of the earth, mineral matter will continue to be brought in by streams, but only pure water can escape by evaporation. Hence mineral salts, common salt, and others, must accumulate in the lake. This process may go on until the water is saturated and deposition of the surplus salts takes place, as in Great Salt Lake, the Dead Sea, and similar bodies of water. A salt lake can only exist when the size of the drainage basin and the amount of evaporation going on in the region is large, relative to the rainfall. Thus the basin of Great Salt Lake is large, has little rainfall, and a very dry atmosphere. Hence, although there is a considerable flow of water from the Wasatch Mountains on the east, the basin can not fill up and overflow its rim. But in earlier times the climate was moist, and a lake of the size of Lake Huron existed, with outflow to the north. Thus a change of climate may cause a fresh-water lake to become salt, or a salt lake to become fresh. Similar results may arise from movements of the land. Thus the valley of Lake Champlain was once occupied by marine waters. By an uplift of eastern North America this valley was cut off from the inflow of the sea, but abundant rains kept the basin full and overflowing, and the salty waters were at length replaced by fresh. The Caspian Sea, on the other hand, retains its salt waters after being severed from the ocean. This is because it occupies a great basin, over most of which rapid evaporation always takes place, and even the Volga can not supply sufficient waters to fill up the basin and produce an overflow. Some shallow lakes in dry regions, as Nevada, receive deposits of mud over their bottoms during the brief period of rains. The waters then

dry away, leaving an incrustation of salts over the mud. The same thing takes place many times, affording alternations of shaly rock and of salt. We shall have further occasion to refer to this process in reviewing the origin of the great deposits of rock salt.

## CHAPTER VII

### THE OCEAN

94. The ocean is indirectly the source of the geological efficiency of water in all its forms. From it all land waters come, and to this common reservoir they all return. The work of the sea is partly destructive, but to a higher degree it is constructive. The greater bodies of sedimentary rock have all been formed upon the ocean's bed, and there also our most connected and full record of the ancient life of the globe has been made. On the whole, such records are destroyed, rather than made, over the lands. But in the sea successive generations of creatures have lived and died, depositing their remains in a growing series of rocks. This phase of the ocean's work will receive constant illustration in the treatment of historical geology, and hence need not be further considered here.

95. **Movements of ocean waters.**—Marine waters are geological agents, particularly of erosion and transportation, by reason of their movements. These movements fall into three classes—viz., tides, currents, and waves.

(1) *Tides.*—On the seashore the water is seen to rise and fall twice in a little more than twenty-four hours. The range of oscillation varies from a few feet on more open shores to more than 50 feet in such inlets as the Bay of Fundy and the estuary of the Severn. The tides are due chiefly to the attraction of the moon, exerted both upon the mass of the earth and upon its less stable mantle of water. In the open sea the tidal wave is broad and imper-

ceptible, but manifests itself on the shore. In estuaries, where the wave is concentrated and may rise to a great height, a rapid inflow and outflow take place, by which erosion and much transportation are effected. On open shores the rise of the tides is so gentle that they have little force;

Fig. 57.—Mud flat at low tide, Minas Basin, Nova Scotia.
(Copyright, 1888, by S. R. Stoddard, Glens Falls, N. Y.)

but they are important as a means of deposit along low shores where tidal flats are growing. The loss of velocity causes deposit as the tide recedes, little movement being generated by the shallow outflowing waters, and the muds being entrapped by grasses and other plants. This principle is used in reclaiming areas from the sea border. An embankment is built about the area, which is easily covered at high tide. Sediments gather in the still water behind the barrier, and the outflowing tide is powerless to remove them. Gradually the surface rises above the tide, or to a plane at which a slight embankment will protect it from further overflow.

(2) *Currents.*—These are broad and massive flows of ocean waters. They are due chiefly to prevailing winds, which in turn depend on the earth's rotation and the difference in temperature between the equatorial regions and those of high latitude. The direction of the currents is largely controlled by the arrangement of the lands. In the Atlantic Ocean a great current moves westward along the equator. Part of this current passes northward through the Caribbean Sea and the Gulf of Mexico, then northeastward past Newfoundland to the eastern shore of Europe, and returns in part southward along the West African coast, completing the circuit. In like manner the rest of the current moves south, east, and north in the south Atlantic. Currents similar in direction occupy the north and south Pacific. One test of the existence and direction of ocean currents is in the transport of objects of known origin. A cask of palm oil set adrift off West Africa came ashore at Hammerfest, Norway, in one year. It had twice crossed the Atlantic. West Indian seeds in like manner make their appearance in Norway. But by far the most important function of ocean currents is the transfer of heat, by which climates in high latitudes are ameliorated, precipitation increased, and a train of aqueous and organic agencies set in motion. The most important illustration of this principle is in the changing of the entire character of western Europe, due to the presence of the Gulf Stream "drift" upon its shores.

(3) *Waves.*—We here refer to the ordinary movements of water produced by winds over more or less limited areas. They become effective on the shore. In the open sea, wave-stirred waters oscillate through a curve of narrow limits,

while only the transmitted energy passes on. But in the shallow waters of the sea margin the wave of oscillation passes into a wave of translation, and for a short distance the water itself may move with great speed and power. This is the principal means by which the sea works out varied results upon its shore. Wave energy which affects the open waters to a depth of many feet is confined to a slight depth near shore. The water rises, rolls over on the wave's crest, the wave breaks and sends its waters up the shelving beach, or dashes them upon the shore cliffs if present. Thus there is an onshore and offshore carriage of coarse or fine materials, according to the strength of the waves and the sources of supply.

There is also erosion, either by the direct blows of the water or of stones wielded as tools by the water. The direct blows of the water are in some cases very powerful. A well-known determination was made on the coast of Scotland. During the summer months it was found that the waves dealt a blow of 611 pounds upon a square foot of surface. During the winter months the force of the blow rose to 2,086 pounds, and in a March gale in 1845 the energy exerted upon a square foot was 6,063 pounds. Such waves drive air into crevices in the rock, and so compress it that it expands vigorously and thus rends the inclosing rocks. It is well here to compare the handling of their weapons by river, glacier, and sea. The weapons are the same; the river drags them rapidly, the glacier pushes them slowly, the sea hurls them vigorously upon the object of attack.

96. **Erosion on seashores.**—On most shores the work of destruction is constant.

> "I with my hammer pounding evermore
> The rocky coast, smite Andes into dust,
> Strewing my bed." EMERSON.

The most effective work is done between high and low tide. But the vertical range of marine erosion is much larger than this. In great storms wave action goes deeper and

Fig. 58.—Sea cliffs and sea cave, Flamborough Head, Yorkshire, England.

rises higher, and the sea erodes powerfully, like rivers in time of flood. A door was wrenched from the Shetland lighthouse by the waves at a height of 196 feet above the sea level. In the same region blocks of rock weighing from 6 to 13½ tons were plucked from the parent ledge at a height of 70 feet above high water. Geikie states the extreme range of wave action, below and above the mean tide level, as 300 feet. But the cases above cited are exceptional, and most work of the sea on its border is accomplished within a much smaller vertical interval. Indeed, we may look upon the sea as a vast saw, operating horizontally upon the lands. We take now the special phases of this work.

97. **Formation of sea cliffs.**—If land of some height passes under the sea by an inclined surface, the sea will cut a

Fig. 59.—Sea cliff, Nahant, Mass.; seaweed covering; high-tide line and effect of inclined planes in the rocks.

notch in the slope, forming a cliff landward with a gently descending floor at its base. The waves attack the foot of

Fig. 60.—Dike eroded by the waves, Spouting Horn, Marblehead Neck, Mass.

the cliff at high tide or in storms, while at low tide the floor is partly exposed, and is always strewn with fragments derived from the cliffs. These fragments are seized by the waves and dashed upon the cliffs for their further destruction. The waves are aided by frosts and by solution, and as the cliff is undermined the upper masses break off, and thus the cliff recedes landward. The character of the cliff depends upon the constitution and structure of the rock. If it be of sand or clay, the cliff may have a moderate or steep inclination toward the sea. If the rock is compact the cliff may be vertical, or may even overhang the sea if the bedding, or joint, or cleavage planes favor it. On some shores no cliffs form, because they are regions of accumulation, and there is constant deposit either of materials brought directly from the land or swept thither by shore currents. The cutting of a cliff is not uniform at all points. If the rocks at a given point be soft, or peculiarly exposed to wave action, they will be cut away more rapidly, and thus sea caverns are formed. In a few cases these extend inward for some scores of feet, as the celebrated cave of Staffa, which is cut for 200 feet into the columns of volcanic rock that form the island. Sometimes the material of a dike is softer than the adjacent rocks. The waves cut away the dike, driving their waters with fierce roar farther and farther into the narrow channel thus excavated. At the inner end the water may be forcibly hurled many feet into the air. This is seen on the shore of Marblehead Neck.

98. **Destruction of land by the sea.**—In the manner described the sea has for long periods been trimming the edges of the continents and islands. This may be seen on parts of Martha's Vineyard and Nantucket Islands, along the shores of Cape Ann, and everywhere on the sea border of Maine. The coasts of Great Britain afford famous illustrations. The south shore of Mull displays magnificent sea cliffs 800 feet high. These show large trespass of the sea upon the ancient area of the land. Staffa belongs to a group of islets which are remnants of an extended formation, and now stand as weird sentinels amid the waters.

The shores of Scotland abound in such displays of the onset of the sea; such are the spectral islands on the north, where the cliffs of Hoy rise 1,200 feet above the waters. The east of England has lost extensively during the present century. Here the waste is rapid, owing to the destructible character of the rocks, which commonly are unconsolidated sands and clays. The landward march of the sea is sometimes several yards per year, and not only farms but a number of villages have been destroyed. As we have seen, this loss is in a general way compensated by the reclamation of the fen lands. On the north and west of England and along the shores of Scandinavia the loss is less rapid, because the rocks are strong.

99. **Limitations of marine erosion.**—If by any means cliffs have been formed which descend directly into water of some depth, the waves have little power. Fragments of rock sink at once to the bottom, below the level of effective wave action, and therefore can not be used as weapons of destruction. If the land keeps a fixed position relative to sea level, encroachment of the sea upon land must be limited to a few miles. Erosion can only be carried to slight depths, and the waters of the new marginal belt must be shallow. The waves of the open sea can not be powerfully transmitted through such waters to long distances.

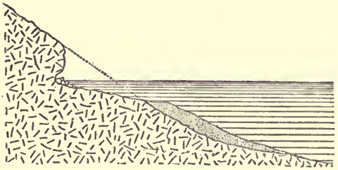


FIG. 61.—Action of the sea on a steep shore line. Cliff with wave-cut and wave-built platform.—After GILBERT.

100. **Beaches.**—The term beach is applied to the narrow belt of rock or of fragmental materials which lies between high and low tide. It is relatively wide or narrow, with a slight or considerable slope, according to the special conditions under which it is formed.

It may have a rocky floor if the force and direction of the waves and shore currents are such as to sweep off the materials of erosion. Commonly it consists of sand, gravel, and bowlders. These fragments will be angular if they have been recently broken from the parent mass, but well beaten and rounded if they have traveled far or have long been ground in the mill of the surf.

Thus beach deposits are usually coarse because only such materials can stay in a zone of vigorous water action. The fine sands are all carried out and deposited at the bottom of deeper and more quiet waters. The rounding of beach pebbles is due to their incessant rubbing upon each other and the blows which they receive in violent wave action. In the reflux of a wave from the shore, the hoarse grinding of stones upon each other may be heard. They are carried in and out by long, sharp zigzags with each onset and retirement of the waves. If there be also a prevailing shore current this tendency will be added, and as a result the fragments may travel alongshore for many miles. Rounded fragments of brick have been found nine miles from the yard where they were made on the shore of Martha's Vineyard. But the total transport of the fragments may have amounted to some scores of miles. Seaweeds often attach themselves to fragments of rocks and to shells. The seaweeds are forcibly attacked by waves, and Professor Shaler has pointed out that large quantities of rock are thus dragged ashore during storms.

101. **Pocket beaches.**—Sand beaches often lie between stretches of rocky shore line. The rocks are broken in pieces by wave action, migrate alongshore, and are gradually ground into fine material, which is deposited in bays or inlets. Such sandy shores are often concave in outline toward the sea, and have been called pocket beaches. If the supply of waste is abundant, the curve approximates a straight line; if meager, it may recede deeply landward. If the waste is migrating alongshore in a fixed direction,

it may consist of coarse gravel and bowlders at one end and of sand only at the other end of the beach. The general effect of the ocean is to cut away headlands and fill

Fig. 62.—Shore cliff and pocket beach of coarse gravel, Long Beach, Marblehead Neck, Mass.

up depressions, thus straightening the shore line, or forming a uniform and broad curve.

102. **Offshore shoals and islands.**—If the sea bottom descends gently, the water will be shallow for some distance. One consequence is that strong waves will break offshore. When the wave breaks and subsides, it deposits its load, and thus a shoal forms. This may soon become an island whose sands are raised into hillocks by both wind and wave. Between the island, which is often elongated and parallel with the shore, is a belt of quiet water, or lagoon. It is possible for small boats to navigate such protected waters along much of the New Jersey coast and other

large portions of our Atlantic shore line. These lagoons tend to fill up with vegetable remains and the wash brought in by streams, and thus in time the islands become a part of the continental surface. On a sinking


Fig. 63.—A straightened shore line, south shore of Martha's Vineyard. Contour interval, 20 feet.

shore line this result is ever delayed. On a rising shore line it is hastened. Many tidal marshes are made in this manner, and form a stage in such growth of the land. As we have already seen, the material deposited at the mouth of rivers may either form a typical delta, or a bar opposite the mouth of the stream, or may be widely distributed, depending upon the strength of the tides and the direction and power of the shore currents. Materials brought from remote parts of the shore by such currents may be carried more or less completely across the mouth of bays and inlets, forming bars or hooks. Currents may also so meet as to form sharp projecting beaches or cusps.

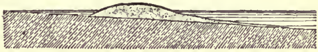


Fig. 64.—Section of barrier beach and lagoon. After Gilbert.

103. **Ice and the sea.**—In arctic latitudes frozen water assumes importance as a marine agent. Along the shore a mass of ice of considerable width and with a thickness of

20 feet or more forms, and is called the ice foot. It attaches itself to the rocks and earth below, and receives deposits from overhanging cliffs. In the spring it breaks up with much rending and redistribution of rocky material. The surface water of arctic bays freezes into massive sheets of ice, which breaks up in summer, and forms floe ice or the

Fig. 65.—Iceberg off the coast of Labrador.

ice pack, entrapping ships, piling up under lateral pressure, with gouging of shallow sea bottoms, or floating off for long distances into the open sea. Floes from Greenland waters may reach Labrador or Newfoundland. The Polaris party of 19 persons drifted on floe ice for 2,000 miles, between October 15, 1872, and April 29th of the following spring. Glaciers entering the sea, as in Greenland, Spitzbergen, and Alaska, and the antarctic region, give off masses of great thickness and bulk, which traverse the seas as icebergs. These are a geological agent of considerable importance and interest. The smaller bergs may be formed by masses cracking off from the glacier front and falling into the water. The larger bergs, however, are buoyed up as a thick glacier enters deep water, and thus they sail away. They may rise 500 feet or more out of the water, but as ice is nearly as heavy as water, only a fraction of the

FIG. 66.—An iceberg which has shifted its plane of equilibrium.

bulk lies above the surface. The relative height above and below vary much with the shape, ranging from $\frac{1}{3}$ to $\frac{1}{12}$ above water. Some icebergs are 1 or 2 miles in length. Fleets of them sometimes invade the temperate latitudes of the Atlantic, chilling the waters and endangering navigation. By progressive melting their forms often become rugged and mountain-like. Many icebergs derived from the antarctic ice sheet are said to be tabular in form.

Icebergs moving in shallow waters may grind and erode the sea bottoms, but not to an important degree. Their chief geological efficiency is by way of transportation. On their surface, or more commonly frozen within and at the base, are bowlders and masses of earth, which may be carried across many degrees of latitude or longitude and dropped in remote seas. Thus the North Atlantic receives every summer a contribution from the arctic lands. If a glaciated pebble should be found in rocks formed in a deep sea, it would not therefore prove that there had been a glacier at that point; it would only show that somewhere a glacier had invaded the sea border.

## The Deep Seas

104. We have thus far referred briefly to the great law that coarser land waste finds lodgment near the shore in comparatively shallow waters, while the fine muds come to rest at greater depths. Organic remains also are deposited everywhere on the floor of the ocean. We shall now give a brief account of the materials of the sea bottom. The conformation of ocean basins will be more appropriately described in Chapter XIV.

The investigation of deep-sea deposits is modern. During the past fifty years expeditions have gone forth with special equipment for observing the phenomena and gathering the sediments of the abyssal seas. Among the most important of such researches are those made by the United States Coast Survey, particularly upon the Gulf Stream. The depth and extent of the oceans render it difficult to gain adequate knowledge of them. It has been well observed that if the continents were deeply covered with waters, such conspicuous features as Mount Etna or the Grand Cañon of the Colorado might long escape observation.

105. **Means of research.**—One of the most important of these is the sounding line, which consists of a steel wire with a self-detaching weight. The dredge is a scoop which brings up a quantity of mud from the bottom,

with the organic remains and living forms which it may hold. Attached to the dredge is a fringe which as a net serves to entangle certain branching forms and tow them to the surface. Similarly a drag is arranged which moves along the surface of the sea and gathers the creatures who live at that horizon. By means of self-registering thermometers the temperature of the sea at all depths is ascertained, and means are also found for collecting samples of the lower waters for chemical examination.

The various groups of marine animals found are preserved and submitted to specialists for deliberate study, and thus in time a minute knowledge of the sea realm in all its parts will be gathered.

106. **Sea-bottom deposits.**—The bulk of the land waste is deposited on the landward side of the 100-fathom line. Below and beyond this line is a transitional zone in which the deposits are of fine mud, but terrigenous—that is, containing particles which can be recognized as of land origin. These muds consist of blue, green, and red marls. They may be found at great depths if the region be not too far from land. The color and composition of such deposits vary with the character of the neighboring lands.

At still greater but not the greatest depths are fine muds, to which the general name *ooze* is given. These consist largely of the entire or dissolved shells of minute organisms, and receive special names from the kind of organism which predominates. They have been studied in an interesting manner by Murray and others. Portions of the mud were mixed with a glue and dried. Small chips of this rocklike mass were then ground so thin as to be transparent, after the usual manner of making rock sections. Much of this mud is called *Globigerina Ooze*, from the great number of shells of this sort. The Globigerina is a minute jellylike creature which secretes shells of carbonate of lime. It lives in the upper waters of the sea, and its shells in infinite numbers rain down upon the sea bottoms.

Other deep-sea muds consist largely of Radiolarians, which secrete shells of marvelously graceful and elaborate forms out of silica. Such muds are called *Radiolarian Ooze.* The siliceous cases of the microscopic plants called Diatoms may also give character and name to these deposits.

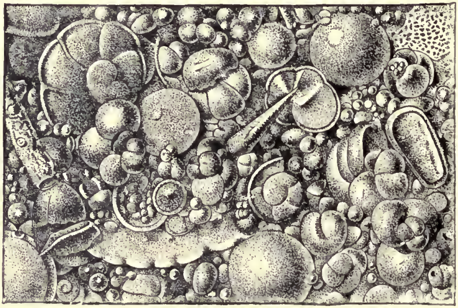


Fig. 67.—Globigerina ooze, as seen in thin section under the microscope. After Agassiz.

At still greater depths, upon the abyssal sea bottoms, lie sheets of *Red Clay.* These extend over very great areas, and are variously composed. They are believed to result largely from the decomposition of volcanic dust and pumice, which falls or is floated extensively over the seas, and sinks at length to the bottom. Other particles are found which are believed to be fragments of meteorites. Concretions of manganese occur, also shells, shark teeth, and other organic remains. These muds accumulate very slowly, and are unlike any rocks now forming a part of the lands. This goes far to prove the permanence of oceans and continents, for the extensive marine rocks of the continents must have been formed in waters of moderate depth.

107. **Life of the deep seas.**—Here we have a great body of facts into which it is not now possible to enter. It must

suffice to observe that each chief group or type of marine animals has some representatives at profound depths. The abysses of the sea are not therefore barren, although they are less populous than the upper waters. It is not easy to picture the conditions of life which there reign. Thus almost complete darkness prevails; hence some deep-sea fishes have large eyes, others have none. The supply of air is small, hence vitality must be low. There is no day, no night, and no change of seasons. All creatures there exist under vast pressure, and it is the one environment which may remain without essential change throughout geological ages. Hence we are apt to find there living forms which are nearly identical in structure with those found fossil in the ancient rocks.

# CHAPTER VIII

## VOLCANOES

108. We may well begin our study with an account of a small but familiar example, Vesuvius. Its cone rises but about 4,000 feet above the sea, and is small, both in height and bulk, as compared with Etna, or many volcanoes of South America, Mexico, or the Pacific Ocean. But since classic times its history is better known than that of any other volcano, and it has therefore a peculiar interest. It rises from the Bay of Naples, and is ever within sight of the famous city, to whose scholars we are indebted for much knowledge of its operations. For many years an observatory has been maintained on the mountain and the university has gathered an extensive library relating to volcanic and earthquake phenomena. Pompeii lies at its base on the south and Herculaneum on the west, while across the bay are Baiæ, Avernus, Misenum, and other localities known in classic literature.

The first eruption of Vesuvius in historic times was that of the year 79 A. D., by which Pompeii and Herculaneum were overwhelmed. Eruptions had taken place on the island of Ischia in times of the Greek settlements, and these may have served by way of a safety valve for Vesuvius. In the year 63 B. C. Spartacus and his band had taken refuge in its crater. In 63 A. D., and following years, earthquakes had occurred which injured buildings in Pompeii. In the year 79 came the great catastrophe, a series of explosions by which vast quantities of volcanic ashes (so called) were

Fig. 68.—Eruption of Vesuvius, 1872.

ejected. It is important to remember that this eruption was without flows of lava. Pliny, the Elder, the famous Roman naturalist, was then commander of a fleet stationed across the bay, at Misenum. He went over the waters to see the eruption more favorably, and in part, as it is said, to rescue a friend. There he was suffocated by the fumes and ash of the volcano. This event is described with great vividness by his nephew in letters written to Tacitus the historian, and thus we have good information concerning the eruption.

The characteristic phenomena were the vast clouds of vapor pouring forth, often taking the form of a pine tree, with brilliant flashes of light alternating with midnight darkness, the falling of a great sheet of fragmental material upon the ground and upon the waters of the harbor, with rockings of the earth and recession of the sea. Pompeii was buried in the ash, and was only rediscovered in 1748. Herculaneum also was covered by ash and volcanic mud.

After various minor outbreaks, another great eruption occurred in 1036, and this affords the first sure record of lava flows from Vesuvius in historic times. Other eruptions occurred in 1138, 1306, and 1631. In 1538, however, on the site of the Lucrine Lake, across the bay of Naples, a hill now called Monte Nuovo was formed by volcanic agency, being reared to a height of 440 feet within a week. In the terrible outburst of 1631, 18,000 persons perished and the skies were darkened as far as Constantinople. Eruptions have been frequent since that time. In 1822 the cone had attained a height of 4,200 feet, and the crater was nearly full. Its contents were blown out, leaving it 1,000 feet deep, while the height of the cone was brought down to 3,400 feet. A segment of the ancient rim, which was broken by the explosions of 79, still remains on the southeast, and is called Monte Somma.

Thus the important facts about Vesuvius are its cone of ejected matter with its many changes of height and form, its explosive and more quiet eruptions of water, vapor, ash, and molten material, and the irregular and intermittent character of its activity. We note also the presence of earthqake shocks and of volcanic phenomena in the vicinity. We are now better prepared for a short, orderly statement of the principles of vulcanism, as this department of geology is sometimes called. We shall then follow with an account of some other volcanoes whose points of likeness and difference are instructive.

## Principles of Volcanic Action

109. **Essential features.**—These are an opening in the earth's crust and a discharge of heated materials. Otherwise the greatest diversity prevails. Thus a cone or mountain mass is no necessary part of a volcano, though numerous volcanoes do form such a structure. Many facts go to prove that the most important eruptions in the history of the globe have taken place through fissures, whence liquid rocks have spread widely without forming mountainous masses.

110. **Active, dormant, and extinct volcanoes.**—Here no sharp division is possible. Who shall say whether the absence of eruption for a hundred or a thousand years is enough to classify a volcano as dormant? Before 79 A. D. the surrounding people might naturally have considered Vesuvius extinct. Still, the distinction is a convenient one for description. Some, like Stromboli, are clearly active, while many others, as we shall see in later pages, are as surely extinct.

111. **Ejected materials.**—These are of four classes: (1) Gases. (2) Water. (3) Lavas. (4) Fragmental matter. We take these in their order.

112. **Gases issuing from volcanoes.**—Chief among these is the vapor of water. According to an estimate quoted by Geikie, $\frac{999}{1000}$ of the cloud which rises over a volcano consist

of steam. But many other gases are disengaged in the subterranean region by the great heat applied to the rocks, and the variety of combinations and chemical reactions which result. Among these are hydrochloric acid, hydrogen and various of its compounds, and carbon dioxide. Exhalations of the last in volcanic regions sometimes cause the suffocation of animals, while the presence of hydrogen may give origin to true flames. It is to be observed, however, that the appearance of flame in eruptions is usually caused by light from molten lavas illuminating the rising clouds of vapor. From the erupted gases various substances accumulate. Such are sulphur, alum, common salt, and others, which may gather in sufficient amounts to have economic value.

113. **Water ejected from volcanoes.**—We have already seen that much water is produced by the condensation of heated vapors. It may also be formed directly by the melting of snows lying on the mountain previous to an eruption, or by the melting of ice, as of glaciers, or masses of ice long buried under slopes of rock waste. The craters of dormant vents may become lake basins, whose waters are invaded when volcanic activity is resumed. We must in addition take account of the water long buried and incorporated with the rocks of the crust, which vaporizes with the melting of the inclosing mass. The water of eruptions becomes geologically significant when it mixes with the friable ash of explosive eruptions and produces torrents of mud.

114. **Lavas.**—Lava streams are commonly thought to be the characteristic product of volcanoes, but it is doubtful whether they are as important as the materials described under the next head. (See section 118.) It is convenient to study lavas under several subdivisions.

115. **Composition and appearance of lavas.**—If lavas contain a large percentage of iron or other metallic bases, they are said to be basic. If, however, they consist largely (60

to 80 per cent) of silica or quartz, they are called acidic. Basalts are basic, while obsidian, trachyte, and rhyolite are acidic. Obsidian is a volcanic glass. Between the two typical extremes all gradations are found. If lavas cool slowly, they may have a highly crystalline structure. If they cool rapidly, they will be structureless and glassy. They are porous, or massive and compact, according to the amount of steam or other vapor contained in them while they are cooling. If the amount is large, the lava may contain many spherical or elongated air pockets, and may be so full of small cavities of this nature as to form a pumice stone, which is used for polishing. It is often so light as to float in great quantities on the surface of the sea. The color of lavas is varied. Basic lavas are commonly dark, while the acidic are often of light colors. Obsidian may be of a transparent blue, or may be even black. In the Yellowstone Park the lavas of ancient eruptions have many hues, in brilliant variety.

116. **Flow of lavas.**—The appearance of a stream of lava varies with the character of the material and the form of the ground. Rapids and cataracts may occur, and lakes are formed behind barriers. The surface often has a ropy appearance. The cooling upper lava is crumpled as the still liquid lower portions push on. Often, in a similar manner, the surface parts are completely broken up, and the stream looks like a creeping mass of jagged and blackened bowlders. The slag from a blast furnace illustrates many of the features of lava streams. Some lavas are much more liquid than others, and this, with different inclinations of slopes, causes great differences in the rate of flow. The lava of Vesuvius, in an eruption of 1805, flowed $3\frac{5}{8}$ miles in four minutes, then much more slowly. A lava stream may creep for months.

117. **Cooling of lavas.**—The surface cools rapidly, forming a crust over which one may walk, even when the under portions are intensely hot. Lava is a poor conductor, and

FIG. 69.—Vesuvian lava flow, 1895.

the rate of cooling of large masses is slow. The lava issuing from Etna in 1787 was still steaming in 1830.

118. **Fragmental materials.**—Volcanoes make an immense contribution to the surface of the lands, and add largely to the formation of the sea bottom by ejection of fragmental matter. Indeed, we should not think of volcanoes (and the same might be said of glaciers) as abnormal or exceptional parts of the economy of the earth. Such material is largely at first in a molten state, blown into dust and bits of larger size by stupendous explosions. This is the origin of the so-called volcanic ashes, which are in no sense products of combustion, but rather of intense, mechanically applied energy. So great is the quantity of such matter that the air may be darkened for hundreds of miles, and the surface of the sea covered for long distances from the seat of the eruption. Darkness prevailed to a distance of 35 miles from one of the Nicaraguan volcanoes, and 24 miles away the ash fell to a depth of 10 feet. Dust from an Iceland volcano has fallen in such quantities as to be shoveled from the decks of ships near the Orkney and Shetland Islands, while in 1783 ash from the same source fell on Caithness, the northeast county of Scotland, so largely as to destroy crops. The season was remembered as the year of "The Ashie."

If the fragments are of the size of a pea and ranging to that of a walnut, they are called *lapilli*. Sometimes huge blocks, either of the older and hardened lava, or of the country rock through which the vent is formed, are hurled to some height and distance. Lumps of molten lava are also cast into the air and cool while under the influence of rotary motion, assuming a variety of pear-shaped and disk-like forms. These are known as volcanic bombs and vary in diameters from an inch or two to one or more feet.

The ejected vapor gives origin to powerful rains, and the water mixes with the volcanic ash, often in mud flows of considerable extent. Such muds, or the ash consolidating in the place where it has fallen, makes the volcanic rock known as tufa, of which there are extensive formations in some volcanic regions. It is porous, but may be quite firm and be used as a building stone. Subterranean dwellings, as in Naples, are sometimes excavated in it.

119. **Volcanic cones.**—Some volcanic eruptions are attended by powerful explosions, with little flow of lavas. A rim is, however, formed of dislodged fragments of the country rock. Such cones are low and broad, and are illustrated in some extinct volcanoes of Italy and the Rhine. A typical cone has a strong slope and a considerable height in relation to the area covered by its base. It

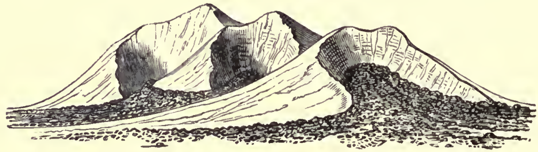


FIG. 70.—Volcanic cones composed of fragmental material, and breached on one side by an outflow of lava.

is not, as was once thought, due to the bulging up of the torn edges of the country rock, but is simply a pile of lava and ash gathered around the opening. Some cones are built entirely of tufa, or consolidated ash; others, though few in number, of lava; while many, like Vesuvius, show beds of tufa alternating with streams of lava. The materials of one eruption are gradually buried by those of later outbreaks, and meanwhile surface streams spread the waste more widely at the base. Gorges cut by streams of water may later be filled with streams of lava, and the shocks of explosions shiver the cone and cause rents or fissures into which the lavas flow. These dikes or walls of cooled lava may intersect the mass in great numbers, serving as girders.

If a cone be built wholly of ash it will be fragile, and a later flow of lava may tear away one side of it. Such breached cones are found among the extinct volcanoes of central France (see Fig. 70). Cones rise not only from the land, but the sea bottom, like those of Hawaii and many other volcanoes of the oceanic islands. Some such cones fail to attain the surface, and are therefore wholly due to submarine eruptions. Others, as Vesuvius and Etna, are believed to have begun as submarine vents opening on a sea floor which has since been raised above the surface of the waters.

### Decadent Vulcanism

120. After powerful eruptions cease, minor volcanic activities remain, to which this general name may be given. We refer to the issues of gas, mud, and heated waters, which may continue even when the volcanic energies of a region have become nearly extinct. An opening through which gases arise is called a *fumarole* (Latin *fumus*, smoke). Hot springs are often formed when subterranean waters come in contact with heated rocks. Deposits of rocky matter from such springs are not extensive, but may be interesting, owing to their characters and form.

121. **Geysers.**—These are a most striking product of volcanic forces. Le Conte has well defined them as periodically eruptive springs. They issue from well-like pools of great depth, and at more or less regular intervals send up powerful jets into the air. These play usually for a few moments only, forming magnificent fountains and sending off clouds of steam. The waters then subside and remain quiet during periods varying from a few minutes to several hours.

Three geyser regions are known—Iceland, New Zealand, and the Yellowstone. The diameter of the jets in the last region varies from 2 to 20 feet and their heights range to 200 feet. The Grand Geyser plays twenty minutes, the Giant three hours. The Grand Geyser erupts but once in thirty-two hours, and Old Faithful at brief intervals. The

Fig. 71.—Old Faithful Geyser, Yellowstone National Park, Wyoming.

heated waters may take silica into solution, which, owing to cooling and relief from pressure, is deposited about the geyser pool.

The heat of the water is derived from subterranean lavas of late geological date, which retain much heat. Thus the Yellowstone Park was the scene of powerful eruptions, as shown by its extensive formations of lava and its tall volcanic mountains. The periodical flow is explained as follows: The water rises through a narrow passage of great depth. The waters far below become very hot, while those near the surface remain comparatively cool, since there is not room for free circulation, such as takes place when water is heated in an ordinary vessel. The lower waters reach the boiling point, which indeed is raised by the great pressure; but at last they flash into steam, producing explosions by which the overlying column of water is forced out, as already described. At length the steam is exhausted, the waters subside, and the quiet heating goes on again, making ready for another explosion. Similar results have been reached by experiments in the laboratory.

## Distribution of Existing Volcanoes

It must be remembered that we here omit reference to many regions in which volcanoes have been active even late in the history of the earth, and confine ourselves to regions where such phenomena have taken place within the memory of men.

122. **The Mediterranean region.**—Here we have Vesuvius and the Lipari group, to which the ever-active Stromboli belongs. These islands contain but 11 square miles, but are inhabited by 12,000 people. Water is scarce, owing to the porosity of the soil. Pumice stone is an export, and the crater of Vulcano was bought by a Scotch firm for its product of alum, boracic acid, and sulphur. Etna will receive description by itself. Off the Sicilian coast an

earthquake was observed in June, 1831. In July a land mass called Graham's Island emerged to the height of 200 feet. By the following year the sea waves had truncated the cone, forming a reef some feet below the surface.

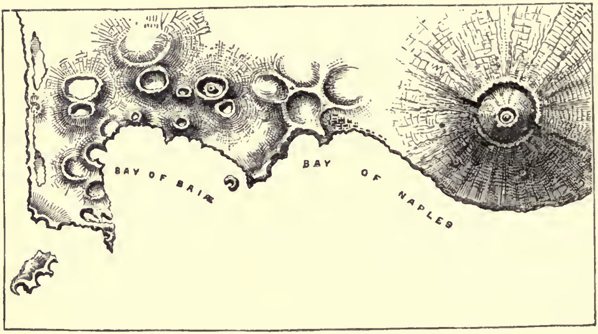



FIG. 72.—Volcanic district about Naples.

In the Grecian Archipelago are the Santorin Islands. Three islands form a rude circuit about a great caldron of sea water. In the midst rises a threefold mountain, one part of which dates from 186 B. C., with additions at intervals since that time. The outer islands have steep inner faces and gentle outward slopes, made up of lava flows. It is evident that these islands are the fringe of a vast ancient cone, whose heart has been blown out by some prehistoric explosive eruption, while activity has been moderately resumed during and since classic times.

123. **Atlantic region.**—A chain of volcanic islands extends north and south in the Atlantic Ocean, though we are not to infer any necessary connection among them. Thus we have St. Helena, Ascension, Cape Verd, the Canaries, the Azores, and then, far northward, Iceland and Jan Mayen. In Iceland we have records for 1,000 years.

Hecla is a cone of moderate height, less than 5,000 feet, and its earliest historical eruption dates from 1104 A. D., the "sand-rain winter." In 1783 on the same island occurred the terrific eruption of Scaptar Jökull. One lava stream was 50 miles long, 12 to 15 miles wide, and 100 feet deep. A river valley was filled to a depth of 400 to 600 feet, the tributary valleys were flooded and villages destroyed.

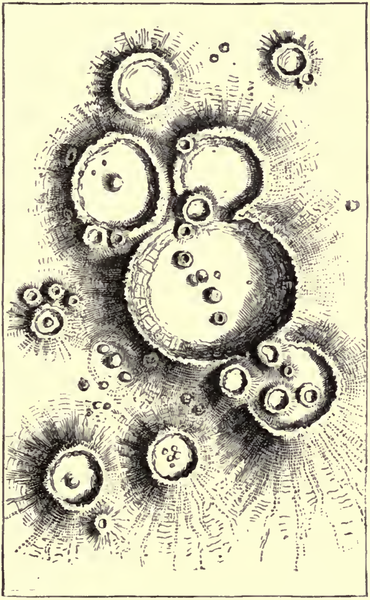


FIG. 73.—A group of lunar craters.

The lava of this outburst is estimated to have exceeded Mont Blanc in bulk. A minor group of volcanoes belongs to the West Indies, chiefly east of the Caribbean Sea.

124. **Circuit of the Pacific.**—Here we have the numerous volcanoes of the Andes, of Mexico, and of the western United States, such as Mount Shasta, Mount Ranier, and Mount Baker, the Aleutian chain, with 30 to 40 cones, Kamtchatka and the Kurile Islands, Japan, the Philippine Islands, New Guinea, Solomon Islands, New Zealand, and the Balleny Islands. Some volcanoes also are scattered in the central Pacific waters, such as those of the Hawaiian, Friendly, Society, and Marquesas groups. Volcanoes also occur on Madagascar, Mauritius, and at other points in the Indian Ocean, while the East Indian region is one of the most important theaters of volcanic energy. The Sunda Islands form an offshoot of the Pacific circuit. Here the single island of Java has 45 volcanoes, of which 28 are active.

More than 300 active vents are known at the present time. It can hardly have escaped the student's attention that the large majority of these are upon islands or along the borders of continents. Only a few important active volcanoes, as some in Mexico, are at any considerable distance from the sea, and those which fringe the continents are commonly associated with great lines of mountainous deformation of the earth's crust.

## Special Examples

It will now be useful to give a short account of some of the greater volcanoes. We take for this purpose Etna, the Hawaiian group, and Krakatoa. These will still further illustrate the general principles of igneous action already stated, and they may also be profitably compared with each other and with Vesuvius.

125. **Etna.**—Like Vesuvius, this mountain has attracted the attention of men since classical times. The Greek philosophers and poets who dwelt in view of the pile sought to understand the mystery of its fires, and in the present century much study and many writings have been devoted

to this great sentinel of the Mediterranean. Etna is one of the most imposing of volcanic cones, because it rises from the sea border, in full relief, to a height of about 10,840 feet. Nevertheless, the diameter of its base, about 40 miles, is so great that its average slopes are but 6 to 8 degrees. Etna began as a submarine volcano in some prehistoric time, and since the uprising of its sea floor the major part of the cone has been built, forming a mass of 20 to 30 times the bulk of Vesuvius. Eruptions have occurred throughout historic times. Although situated in a subtropical region, Etna rises above the forest zone to regions of perpetual snow. A mass of ice on the mountain side has for many years been covered with a stream of lava, and torrents of water that sometimes accompany eruptions are due to the melting of the snows.

An important feature of Etna is its minor cones, about 200 in number. These are formed on the slopes by outflows through fissures, and some of them attain a height of 700 feet. These subordinate cones may be either destroyed or covered by later eruptions. If we could make complete vertical sections of Etna, or could peel up its successive sheets of lava and ash, we might find a great number of such cones. In 1669 six fissures appeared on parallel lines, one of which, as quoted by Geikie, extended for 12 miles and was 2 yards in width, shining with its fiery lavas. Another feature of Etna is the Val del Bove, a profound gorge or basin east of the present crater, believed to have been opened by a stupendous explosive eruption and to occupy the place of a former vent.

126. **The Hawaiian volcanoes.**—All the islands of the Hawaiian chain are volcanic, but Hawaii, the largest, contains all the active vents, three in number. Of these, Mauna Loa, near the center of the island, is the highest, 13,675 feet.

The Hawaiian cones are very flat, having slopes of 1 to 10 degrees. In this they contrast with such steep cones as Mount Shasta and Mount Ranier of the Pacific slope. The craters are wide, sunken fields, with steep walls, 400 to 1,000 feet high. Much of the floor of the craters is a crust of cooling lava, with lakes of still molten matter, which may boil quietly or send up violent fountainlike jets. From time to time masses of the crater wall crack off and sink

Fig. 74.—Hawaiian lava flow. Photograph by Libbey.

down, and thus have formed in some places a series of gigantic steps. These crater basins are roughly elliptical and have diameters of 2 to 3 miles.

Previous to the eruptions of 1832 and 1840, according to Dana, the lava had slowly risen about 400 feet in the crater of Kilauea. In each case this had occupied eight or nine years. Eruption, therefore, must take place not over the rim of the crater, but through fissures, and thus the lava stream first appears at some distance down the mountain side. The lavas are of the more liquid sort, and often flow for long distances. The hydrostatic pressure of the great column of lava in the conduit overcomes the resistance of the mountain before the lava can be pushed to the top, hence the fissure eruptions. The lava stream from Kilauea in 1840 reached the sea, a distance of 30 miles, and formed a fall a mile wide over the sea cliffs. A stream from Mauna Loa in 1880 threatened Hilo, on the east coast, 33 miles from the crater.

Hawaiian volcanoes furnish an instructive contrast with Vesuvius in the liquidity of their lavas and consequent flatness of their cones, in their wide caldron craters with faulted rims, and in their more prolonged and quiet eruptions, predominating in molten rather than fragmental products. Students who wish to study this island group more fully should consult Dana's Characteristics of Volcanoes and Dutton's Report on the Hawaiian Volcanoes, the latter in the Fourth Annual Report of the United States Geological Survey.

127. **Krakatoa.**—This volcanic island lies in the Sunda Strait, between Java and Sumatra. On May 20, 1883, premonitory signs of the great eruption which followed began to be observed. There were sounds like artillery, earthquake shocks, and clouds of ash. On August 26th to 28th terrific explosions took place, by which a large part of the mountain was destroyed. Lamps were lighted in the daytime in surrounding regions, and quantities of pumice fell on the decks of such ships as were sailing in those waters. So unusual was the display of fiery energy that the eruption has been made the subject of careful investigation and special report, both by the Royal Society of Great Britain and by the Dutch Government. According to Verbeek, the author of the latter report, the fine dust rose to a height of 50,000 feet. Such dust fell on ships 1,600 miles away, and is generally believed to have been swept around the world.

To it are attributed the lurid red skies which were observed in America during the months of the following autumn.

Perhaps the most interesting results of the eruption were the atmospheric and sound waves and water waves generated. The atmospheric waves were seven times repeated around the globe. The explosions were heard to almost incredible distances, as at Bangkok, 1,413 miles; Australia, 2,000 miles; Ceylon, 2,058 miles; and at the Chagos Islands in the Indian Ocean, 2,267 miles. It was as if an explosion in New York were heard in the Bermudas, Newfoundland, Duluth, New Orleans, and Denver. Water waves are believed to have swept over half the globe. It is probably not too much to say that this single eruption affected the entire planet.

## The Causes of Volcanic Action

128. No conclusive word has been spoken on this subject. A final conclusion may lie beyond the bounds of human investigation. As with the glaciers of the Ice age, earthquakes, or the origin of species, many facts are known and some major conclusions can not be doubted, but the ultimate cause yet lies in obscurity. This is not discouraging to the true student, but only one of many proofs of the limitation of our knowledge.

Two questions must be asked: (1) What are the sources of the heat needed to melt the rocks and form the gaseous clouds of vast extent? (2) What is the force that expels these materials from the crust? As regards the first, many answers have been given which must be set aside, or at least appear to be inadequate. Volcanic heat has been thought to be a remnant of the original heat of the globe. But on this theory it would seem that vulcanism should gradually have declined through the ages of geological history. This has not been proved, and some facts look in the opposite direction. Others have thought that the heat comes from powerful chemical reactions in the deep natural laboratories of the earth's crust. But this cause seems insufficient for the melting that is accomplished. It is known that rocks melt and become plastic, under great pressure, in the presence of water and alkaline materials. This is called aqueo-igneous fusion, but does not account for the great heat of volcanoes. All these causes may contribute to the result in various degrees and localities. Thus the original heat of the earth is believed to hold the rocks of the crust near the melting point at no great distance below the surface. Such crushing as goes with mountain-making may add heat enough of mechanical origin to cause fusion. A seemingly paradoxical theory is that the under rocks would melt if they were not under stupendous pressure, and when at some points this pressure is relieved in the succession of strains which the crust undergoes, the rocks there pass into a molten state. The two theories are not inconsistent. At one point we have added pressure and added heat; at another, removal of pressure and lowering of the melting point.

As to the cause of explosion, the answer is hardly more satisfactory. The sudden conversion of water into steam is thought to have much to do with explosive eruptions, and the more as most volcanoes are near the sea. But this does not account for inland or quiet eruptions. Nor is it easy to see how enough water could reach the seat of the heat, either by saturation or sudden inflow. Chains of volcanoes, as in the Andes, correspond with lines of mountain-making. A perfect theory must explain all the facts. Why are some eruptions quiet and others violent? Why the differences in the composition and heat of lavas? Why should there be a difference of 10,000 feet in the height of the lava columns in the adjacent volcanoes of Mauna Loa and Kilauea? Why are some vents intermittent and others constant in action? Such are some of the questions. No theory covers all of these.

# CHAPTER IX

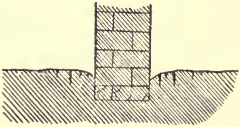
## MOVEMENTS OF THE EARTH'S CRUST

129. THESE may be roughly subdivided into three classes, which are treated in the following pages. We may have movements with shock or earthquakes, gentle upward and downward movements or oscillations, and movements producing folding or deformation. The last two are imperceptible as processes by the ordinary means of observation, but may at intervals be accompanied by the first.

### I. EARTHQUAKES

130. As with volcanoes, so here we shall find it profitable to begin with a concrete example. We choose the Charleston earthquake of 1886.

Slight shocks had occurred during the summer months, and the great shock took place about 9.50 P. M., August 31, 1886. It lasted sixty to seventy seconds. All the buildings of Charleston were affected, and many seriously injured. The peculiar wave motion of an earthquake was powerful and destructive. The amplitude of the wave, or measure of sidewise motion, was 3 to 4 inches. The worst effects were produced on land formed by reclaiming parts of the bay. The waves traveled across country at the rate of 150 miles per minute. The epicentral tracts—that is, the places directly over the centers of disturbance (for there were two)—were at Woodstock, 16 miles north-northwest of the city, and at a point 13 miles west. At these points were evidences of vertical movements, such as sunken piers and joists lifted from their positions. As one receded from the centers evidences of lateral thrust were found, especially sharp bends in the railway tracks passing both places. At some places craterlets opened, and water stained with earth was belched into the air.



Scale ⅛ in. = 1 foot.

FIG. 75.—Section of pier driven downward by earthquake, Charleston, 1886.

The depth of the focus was determined as about 12 miles. The sounds were described by the terrified people by a remarkable variety of illustrations—"thunder in the ground"; "roaring of a prairie fire"; "troop of cavalry crossing a long bridge"; "running of heavy machinery in basement of houses"; "train of cars at a distance"; "escape of steam from a boiler,' and many others. This roar is ascribed to the vibration and clash of many objects, and is well likened to the aggregate of sounds in a great city.

A wide territory felt the shock. The region of sensible shaking is given as a circle having a radius of 1,000 miles, an area of about 2,500,000 square miles. Shocks exciting special attention were felt in New York, in Cleveland, in the province of Ontario, and in the Mississippi Valley as far west as Iowa and Missouri. Much of Pennsylvania was a region of "earthquake shadow." Valuable determinations of the rate of transmission of the shock were made

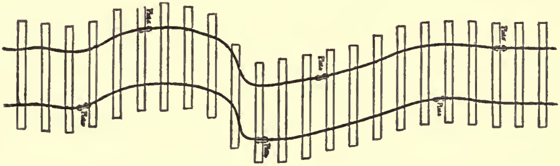


FIG. 76.—Bends in railway track near Charleston, made by earthquake, 1886.

because of the wide use of standard time, which made possible a careful comparison of the time when the disturbance was felt in widely remote areas. The investigation, prolonged as it was, gave no clew to the ultimate cause of the earthquake.

*Principles of Earthquake Action*

131. **Definitions.**—An earthquake is a trembling or shaking of a part of the earth's crust. It may involve simple wave motion or it may produce a permanent displacement. Seismic (Greek, *shaking*) is an adjective synonym. Seismology is the science of earthquakes, and includes an extensive literature. The focus is the subterranean center

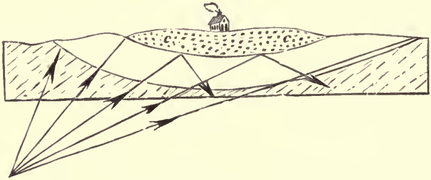



Fig. 77.—Building unaffected because resting on soft, inelastic strata, *c, c.*

of disturbance or the point where the energy is applied. The epicentrum is the point on the surface directly over the focus. The seismic vertical is a straight line joining the focus and epicentrum. Earthquakes are closely imitated by some shocks of artificial origin. Thus the explosion of Hell Gate for deepening the passage between the East River and Long Island Sound started waves of movement in the rocks which were felt in Boston, 200 miles distant. Similar vibrations are often felt from blasting in quarries, the firing of heavy guns, and the passage of cars over hard or frozen ground.

132. **Earthquake waves.**—As described by Le Conte, an earthquake is caused by the arrival at any given point of

an elastic compression wave. Even the hardest rock is more or less compressible, and force applied is transmitted to a greater or less distance, according to its original strength and the elasticity of the medium. The waves

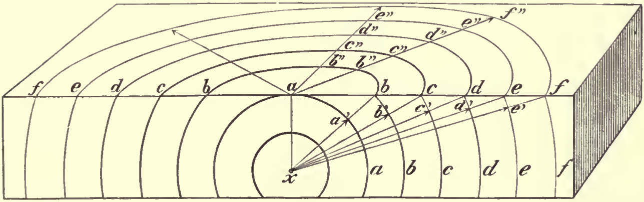



Fig. 78.—Diagrammatic view of a part of the earth's crust shaken by earthquake. *x*, focus ; *a*, *b*, *c*, *d*, sections of spherical waves ; *b''*, *c''*, *d''*, perspective of surface wave.—After Le Conte.

that pass up from the focus emerge at right angles to the surface, and cause an upthrow of surface objects, as seen in the Charleston earthquake. Other waves emerge at less angles until, at distant points, they move in lines nearly parallel to the surface (Fig. 78). By observing the relations of the various dislocations and fractures it is often possible to determine the position of the epicentrum and the depth of the focus. The amplitude of a wave is the amount of actual movement of the particles affected. This in earthquakes is given by Dana as varying from less than a millimeter to possibly a foot.

The rate of movement depends on the character of the rocks. If they be spongy and soft, the rate is less, as also if the rocks are much crushed and fractured. It is also, however, commonly true, as in the Charleston disturbance, that buildings suffer more upon the softer rocks, even though the wave moves more slowly. Slight shocks are apt to travel more rapidly, perhaps because the crushing of the rocks is in less degree. Waves have been felt in mines which were not sensible at the surface, and have been imperceptible in one place while evident in surrounding places. All such facts point to the variable capacity of rocks for transmitting wave motion. For this reason waves do not spread to equal distances in all directions. Thus the area affected by a shock may be elliptical, linear, or irregular in form. As light waves may be reflected or refracted in passing from one medium to another, so may earthquake waves in passing from one kind of rock to another.

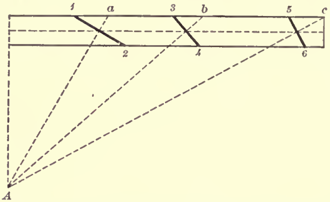



Fig. 79.—Emergence of earth wave from *A*, at *a*, *b*, and *c*, may produce fractures having the direction *1—2*, *3—4*, and *5—6*. From such cracks the position of focus *A* may be determined.

133. **Water waves due to earthquakes.**—Such are often of great magnitude and destructive power. They are "forced" waves, and the student should never commit the error of calling them tidal waves. They sometimes move at the rate of several hundred miles per hour. Not seldom withdrawal of the waters from the shore region is followed by a stupendous onrush. Such waves may cross the widest seas. During the Samoda earthquake in Japan, 1854, the bottom of a bay was exposed, where commonly there were 30 feet of water. The town was next flooded to a depth of 30 feet, and this occurred several times. Other illustrations will be given in the account of particular earthquakes.

134. **Distribution of earthquakes.**—Such movements have been common throughout the geological ages, and occur more or less frequently in nearly all parts of the earth. Like glaciers and volcanoes, therefore, they are not to be thought strange or peculiar, but are a normal phase of the earth's development. They occur in nearly all volcanic regions, but are by no means confined to these, as is shown

by their occurrence in the eastern and central parts of the United States. We must remember, however, that historic records in America are brief. Professor Shaler has cited evidence that destructive earthquakes have not occurred in New England since the glacial times. This is indicated, for example, by the perched bowlders, which would otherwise have been thrown down from their unstable positions. The presence of frail rock structures, such as erosion pillars, suggests similar freedom from agitation for other parts of the country. Still, slight shocks are not seldom observed in the eastern United States, and are somewhat frequent on the Pacific coast. The western border of South America is the scene of most frequent and destructive shocks. Earthquakes are not uncommon in the Alps, and in general abound in the region of the Mediterranean, in southern Asia, and among the volcanic islands of the Pacific. They have been observed by Milne in Japan, where they may average one for every day for considerable intervals, and where some have been terribly destructive. Slight shocks are occasionally felt in the British Islands, especially in Scotland. Le Conte expresses the opinion that at all times some part of the earth is shaken by earthquakes.

135. **Geological effects of earthquakes.**—These are quite various, but only occasionally important. Fragile rock masses may be broken or thrown from their places, and soils or masses of talus jarred down the slopes on which they rest. Planes of jointing, cleavage, and bedding may be opened to air and water, and cavernous masses of rock shaken down. Landslips are precipitated, as in some instances in the Alps. Fissures may be formed or widened, facilitating the circulation of waters, the making of veins, and metamorphic changes in the rocks. Some permanent changes of level have resulted. Possibly the greatest effect of earthquakes is the destruction of colonies of marine creatures, either by the shock or by the agitation of the

fine sediments which would be fatal to some forms of life which flourish in clear waters.

136. **Construction of buildings.**—It is obvious that in regions subject to shocks, buildings should be of moderate height and solid construction, either of wood or of thick walls of good material, well bound, and upon the best foundations available. It is not impossible that disaster may thus befall the occupants of the tall buildings of modern American cities. Even the waves of the Charleston earthquake were felt to an unpleasant degree on the upper floors of the Herald Building in New York.

137. **Special illustrations.**—We have already given an account of the Charleston earthquake. Seventy-five years earlier, in 1811, a noteworthy series of shocks took place in the vicinity of New Madrid on the Mississippi River in Missouri. This is also a great distance from any volcanic region. Powerful ground waves moved across the country, swaying the forests and often causing the tree tops to interlock. The ground was cleft with fissures, which ran in a fixed direction, insomuch that the inhabitants felled trees in a line at right angles to that of the fissures in order to find safe refuge upon them. Some areas sank so that trees were left standing in water, and new lakes and islands were formed along the Mississippi River. Boundaries of property were thrown into confusion, and the Government is said to have made a reissue of lands to the extent of 1,000,000 acres. The whole district is one of extensive river deposits, and this may account for the frequency of the fissures and the sunken areas.

In the following year a most disastrous earthquake visited Carácas in South America. The ground undulated like boiling waters, and the city was instantly destroyed, with the loss of 10,000 lives.

One of many other severe South American disturbances occurred in the region of Chili on February 20, 1835. The agitation had a north and south range of 1,000 miles, and was felt for 500 miles in an east and west direction. The retreat of the waters was so great that vessels in seven fathoms were grounded, while, by the onrush of the great forced wave, a man-of-war was driven over houses on the shore. A submarine volcano opened in 67 fathoms of water, and the land was rent by fissures. The most important geological result was that the area about Concepcion was permanently raised several feet, so that the marine organisms which had lived near shore were left to perish. A similar uplift had occurred in Chili in 1822, and it has been computed that 57 cubic miles of matter were lifted from below sea level to a position above it. This equals the amount of solids carried out by the Ganges in four centuries. This is an instructive comparison of uplifting and down-wearing operations. A catastrophe took out of the sea as much rock as a great river could carry back in 400 years. Lyell supposes the focus to have been 10 miles deep, and on this basis concludes that in the 100,000 square miles affected 1,000,000 cubic miles of rock were lifted. Such displays of force are quite beyond our understanding,

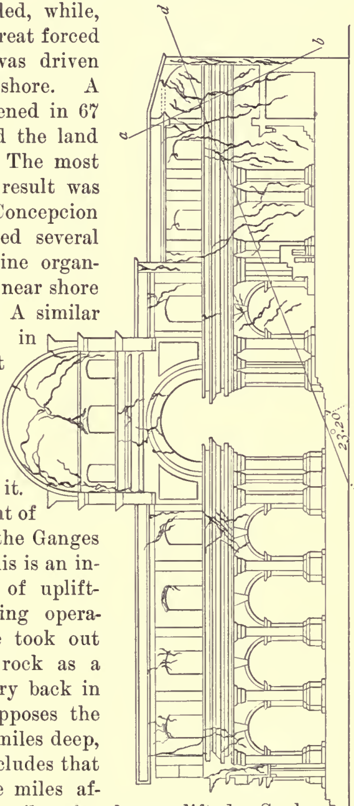



Fig. 80.—Cathedral church, Potenza, shows method of using fractures to determine angle of emergence of earthquake wave. After Mallet.

but have been of frequent occurrence in the history of our globe.

Our next example is a New Zealand earthquake of 1855. It is a region of earthquake disturbances. In the year 1882, for example, 28 shocks are reported, 1 severe, 10 "smart," and 17 slight. That of 1855 was forcibly felt about Cook's Strait, which separates the two greater islands, and affected 360,000 square miles. On the south shore of the northern island a band of lowly marine organisms called *nullipores* incrusted the rocks. After the shock these were found at a height of 9 feet above the tide. The beach also, at the foot of the cliff, had afforded a passage for cattle only at low tide, but was now passable at all times. This uplift was traced inland for 90 miles. Across Cook's Strait the movement was one of depression. Ships had been accustomed to sail up the Wairau River for supplies of fresh water. They were obliged to go 3 miles farther to pass beyond the reach of marine water after the earthquake. It must not, however, be thought that these sudden uplifts are the chief way in which the lands have risen above the sea. We shall later see how this is usually done without shock or observation.

The greatest European earthquake of modern times took place at Lisbon in 1755; 60,000 people perished within six minutes. A marble quay on which a throng had gathered to escape from falling buildings sank beneath 100 fathoms of water. Neighboring mountain sides were shattered, and the sea wave was very powerful. A concussion was felt at sea, and at the sea border there were recession and onrush. The wave was 60 feet high at Cadiz, and 15 feet off the Madeira Islands. It was strongly felt in the harbor of Kinsale, Ireland, where ships were whirled about and the market place flooded. The tremor was detected in Sweden, in the Alps, in North Africa, and on the Great Lakes of North America.

### *Causes of Earthquakes*

138. There are doubtless several ways in which energy can be suddenly applied to the rocks. Many shocks result from volcanic explosions, and are really therefore products of volcanic action, and due to the same causes. But the greater number of earthquakes are probably due to the shrinking of the earth's crust in cooling. This is not the place for more than a notice of this important subject. It must suffice here to observe that a comparatively stiff crust over a cooling and shrinking interior must also shrink. It becomes cracked in some places and folded in others. Stupendous strains are thus set up and rock masses are liable to move suddenly upon each other. Rock walls or beds are held against each other by inconceivable pressures, but even such friction may be overcome and sudden slips occur. All points to which the impulse is transmitted experience an earthquake.

It has been found that earthquakes occur in some regions more often in winter than in summer, and that they are more frequent in certain phases of the moon. It thus is plain that the balance of forces is delicate, and may be broken by change of atmospheric pressure and by the attraction of outside masses of matter.

If the shrinking of the earth's outer crust of cooler rocks be, as above supposed, the greatest cause of earthquakes, they are the symptoms or incidental accompaniments of the quiet but more stupendous movements which are next to be considered.

## II. Oscillations

139. This term is applied to gentle and long-continued movements, by which parts of the earth's crust rise or sink. The amount of elevation or subsidence is measured with reference to sea level, which is generally believed to be practically stable. Such movements are so slow that they

can be detected only by careful observers, and by comparisons made at long intervals. And yet they are among the most important changes which affect the globe. Mainly by them in all ages have the sea floors risen out of the water to form existing continents. By them lands of unknown extent have been buried beneath the sea.

140. **Proofs of elevation.**—The proof that elevations of large areas have taken place in distant periods lies not only in the presence of marine fossils in rocks hundreds or thousands of feet above the sea, but also in the fact that such elevations are now in progress, and have been in operation in historic and immediately prehistoric times. If barnacles, which attach themselves permanently to objects within reach of the tide, are found above high-tide limit, we have a proof of recent elevation. The same is true of borings of marine mollusks or other evidence of the presence of marine organisms above where they could now live. We must make sure, however, that such remains have not been moved from their original relative positions.

Products of erosion above tide, or above storm levels, have the same value. Such are sea caves and raised beaches, whether they are notches cut, or embankments built, on hill or mountain slopes, where no waves can now work. Such beaches exist about the basins of ancient lakes which have been destroyed or made small by evaporation or drainage. These are to be distinguished from ancient sea beaches, which can only be due to rising of the land. Such beaches are wide and strong in proportion to the time during which the land remained at that level. A succession of such beaches on a slope above the sea means that there were successive periods of elevation, alternating with periods of stability. Works of man, such as piers, are now sometimes found elevated and removed from the sea. Distance alone can not be taken as proof of elevation, because the sea may be crowded off by filling, as in so many delta regions. Storm beaches also might be taken as proofs of elevation by those who are strangers to the power of the sea.

141. **Regions of present or recent elevation.**—Since the glacial time the coast of Maine has risen at some points somewhat more than 200 feet. Similarly many points to the north, as Labrador and Newfoundland, have risen, though some points along intermediate coasts are sinking. Terraces of recent coral limestone are found on the shores of Cuba several hundred feet above the sea level. Elevated beaches are common about Great Britain. Along the coast and among the islands of western Scotland one may follow the 25-foot beach for long distances. Scandinavia is a well-known illustration. Its shore line is slowly rising except south of Stockholm, where a slight subsidence is in progress. The uprising increases going northward to a maximum of six feet per century, according to Baron de Geer. Sea terraces or old beaches are found far inland and up to a height of 600 feet.

There is no clearer or more interesting example than that afforded by the three remaining columns of the Temple of Jupiter Serapis at Puzzuoli, near Naples. These stand at the water's edge, and were erected at the beginning of the Christian era. At about 20 feet up they bear a broad belt of perforations made by boring sea mollusks. These prove that the place has sunk 20 feet since the temple was built, that it remained under water long enough for the borings to be made, and that it has now risen to about its original relation to the sea. Such an oscillation in a volcanic region may affect less territory than similar movements on the east coast of America or in the north of Europe.

142. **Proofs of subsidence.**—Forests or stumps standing as they grew and now submerged in sea water are proofs of subsidence. Precisely the same is shown by submerged beds of peat. As evidences of elevation are destroyed by erosion, so these proofs of depression are easily buried by

sediments. But there are other evidences of depression less easily destroyed. Thus the animal or plant forms on two sides of a water passage may be so similar that both groups must have had a common beginning, and have been cut apart by the sinking of the intervening land. Such is the relation between the organisms of some East Indian islands and Australia.

Another and most important proof of former subsidence is the series of fiords or "drowned" valleys which characterize the eastern coast of North America, the shores of Scotland and of Norway. The inlets of the Hudson or Narragansett and of the Saguenay, or of the firths of the Forth and the Clyde, are typical examples. The sea can not cut out such valleys extending far inland. They were formed by the common means of valley-making when the land was higher than now, and on the down-sinking of the land the lower valleys were drowned, resulting in estuaries like the Hudson, bays like Narragansett, and sea lochs like those of Scotland.

143. **Regions of subsidence.**—About Cape Ann, at Newburyport, and on Nantucket Island recent subsidence of a few feet has been shown. Likewise the geologists of New Jersey believe that the shore line gives evidence of recent sinking at the rate of two feet per century. They cite as evidence meadow turf covered with some feet of water, the encroachment of water upon the shell heaps of prehistoric dwellers, buried corduroy roads of early settlers, the dying off of trees at the seaward edge of fields, and the migration of oysters up the streams. Southward the great inlets of the Delaware and Chesapeake Bays are true fiords, though the bordering lands fail of the mountainous heights of the Hudson and of Norway. The Chesapeake and its tidal rivers occupy just such a group of valleys as would be made by an ordinary river system. Such is their origin, and submergence has caused the present conditions. Forest remains buried several hundred feet below the level of

the Gulf of Mexico at New Orleans prove late sinking of the Mississippi Delta district. The great series of deep inlets on the Pacific coast from the Golden Gate to Alaska proves subsidence. As this is written there appears notice of studies undertaken by Mr. G. K. Gilbert to determine what the present movements are on the Pacific coast.

Six hundred miles of the south Greenland coast have been sinking during recent centuries. Houses once high and dry are now washed by the tide, and in some cases low islands have been covered, leaving the remains of buildings standing out from the water. So, as already mentioned, the southern part of Sweden has recently undergone subsidence, though the present continuance of this is questioned. Past submergence is proved by the rising of sea waters upon parts of the village of Scania. We here find an important principle, namely, that neighboring places may oscillate in reverse directions. Similarly the vast subsidence which Darwin's theory of coral islands demands for the central Pacific is believed by many to have been accompanied by the stupendous mountainous uplifts of western America. Similarly subsidence has been shown for the coasts of Devon and Cornwall, which may be put over against the late uprisings of the northern shores of Great Britain. The earlier history of the Temple of Jupiter Serapis shows subsidence, and the same process is now reported to be again in operation there.

144. **Warping.**—It is now well for us to try to picture the character of movements as they take place over great regions. So long as the crust is not broken the uplift or down going must be more in amount in some places than in others. It culminates at one point or along an axis, and fades out in all directions. An uplift is therefore a very broad swell whose height is relatively insignificant. If in a given region one part goes up or down faster than another, or one part goes up and another goes down, such varying movement is called warping. Gilbert has shown,

with a close appreach to demonstration, that such a warping is now going on in the region of the Great Lakes. The tilting is toward the southwest, and by it, if it continues for a few thousand years, it is claimed that the waters of Niagara will be turned across Illinois into the Mississippi River. The rate of warping is 5 inches per century in a distance of 100 miles. It is not shown whether the movement is all upward at varying rates, or whether this great region is turning as upon a fulcrum.

145. **Causes of oscillations.**—Here we must meet the obscurity which attends the whole problem of the interior of the earth. Physicists and geologists of the present day ascribe these changes mainly to the slow shrinking of the earth. But it is not denied that other causes may contribute something to the result. Thus (1) sea level itself may slightly vary, owing to the attraction of great continental and mountain masses or extensive ice sheets. (2) Heat invading masses of rock from below may cause expansion and uplift. (3) Loading and unloading, as by erosion in one place and deposit in another, may affect the stability of the crust. A great thickness of coarse sandstone, a rock which could only be formed in shallow water, proves subsidence, which may be due to loading. In like manner the gathering and melting off of an ice sheet over hundreds of thousands of square miles may promote oscillations. But none of these causes can explain the first uprisings of land from primeval waters.

### III. Movements of Deformation

146. **Definition.**—Such movements can not be sharply marked off from oscillations. But they include in a general way all changes of position of parts of the earth's crust by which considerable folds are made or dislocations produced. An oscillation is a slight bend up or down. By folding, arches of considerable height and troughs of large depth are formed. There may be all gradations be-

tween the two. It is by deformatory movements that typical mountain chains have their origin. It will be more convenient to study mountain structures and mountain-making at various points in our account of structural and historical geology. The subject is briefly introduced here because the forces at work are believed to be the same with those that cause oscillations and many earthquakes.

If a broad upward swell takes place over a part of a continent, we have an oscillation. If there be a zone of weakness and the energy is applied long enough and powerfully enough, a series of folds and breaks will be caused, forming mountains. In the upswelling, and especially in the crumpling, sudden shoves or reliefs will cause earthquakes. All the movements concerned, save at such times as earthquakes occur, take place with exceeding slowness.

# CHAPTER X

## GEOLOGICAL WORK OF ORGANISMS

147. THE most stupendous changes are produced in the form and structure of the earth's crust by great rivers, glaciers, volcanoes, and the waves of the sea. But we have already seen that equally important effects are due to the quiet but constant activities of the atmosphere. In like manner living creatures, plants and animals, work silently, but produce results which perhaps compare in significance those of any other geological agent. We take first—

148. **The work of plants.**—Plants cover the greater part of the land. The exceptions are the rocky slopes of the highest mountains, regions covered perpetually by ice and snow, and a few very dry districts. In the last, however, some vegetation modified to suit its special environment always flourishes. Everywhere the mantle of vegetation is nearly unbroken, whether of dense forests, shrubs, or herbaceous plants. Their effects on the earth's surface are most varied; in fact, they are inextricably woven together. For convenience of study, however, we must seek to analyze them and discuss them one by one. The geological efficiency of plants is at once protective, destructive, and constructive.

149. **Protective effects of plants.**—Plants serve to shield the soil from erosion by streams, rain, and wind. They may also prevent the frosts from reaching a depth which they would otherwise attain. Many hill slopes have remained without much change since the close of glacial

times, a period of at least some thousands of years. This would be impossible but for the forest cover, and the network of roots which keeps the water from gathering into channels of erosion. This is evident from the fact that such slopes are often deeply gullied by wet-weather torrents within a few decades of years after the forests are cut away. Roots and fallen leaves and the entire body of living and decomposing vegetation serve as an absorbent mass to hold the water, to moisten the soil for further growth of plants and to avert floods.

Trees often, though not always, as we have seen, avail to prevent or retard the descent of avalanches. We have also observed their value, whether propagated naturally or by the hand of man, in checking the migration of dune sands. They also serve as windbreaks, as in Nebraska and elsewhere on the plains of the West.

150. **Destructive effects of plants.**—Wherever the roots of trees reach down to the rock, they insinuate themselves into its crevices, and as they grow they help to rend the blocks apart. Trees often grow on rocky slopes and on the edge of cliffs where there is little soil, and the roots are apparent as they rest upon and descend between the blocks of rock. It is most common to see slabs partially wedged off and nearly ready to fall to the bottom of the cliff. Roots of trees have been followed to a distance of some scores of feet from the parent stock. Thus not only do the large roots rend the rocks and heave the soil, but a great body of rootlets is provided, contact with which promotes disintegration. While plants withdraw moisture from the soil, they also may mantle the earth so effectively from the direct attack of the sun as to retard evaporation, and promote the solvent activity which water always exercises upon rocks and soils.

151. **Constructive effects of plants.**—These are chiefly by way of accumulations of vegetable remains. The most important of these accumulations is the mantle of decayed

vegetation which everywhere makes up a part of the true soils, and is most conspicuous in forests and the deep black soils of the prairies. We also find important accumulations in special situations. Thus on the shores of Florida flourishes the mangrove, which has the special habit of sending out branches and dropping its roots through the

FIG. 81.—Rocks wedged apart by growing tree, western Massachusetts.

shallow waters of the sea margin. These roots entrap leaves, waste from the land, and remains of marine organisms, and thus little by little reclaim areas from the sea. Driftwood may accumulate in streams, even to the formation of a solid barrier across them. Such a barrier was the great raft blockading the Red River in Louisiana for a distance of several miles, until it was cut away. Such blockade would retard the flow of the stream, hold its waters to a higher level, and thus change the geological condition of large areas.

Wherever for any reason drainage is imperfect, vegetation of water-loving types flourishes, and we find the deep black earth, and in favorable conditions the peat of swamps. Thus swamps occur on the flood grounds of great rivers, in tracts left without free outflow by accumulations of glacial times, in the inequalities of land surfaces recently elevated out of the sea, on the sea border, and even on hill and mountain slopes of considerable inclination, if the climate be cool and the supply of spring water abundant. In the shallow waters of lake borders vegetable accumulations are important, and when small or shallow lakes become nearly filled in with sediments from the land the whole area may become a swamp and a field of organic deposit. Thus in a general way much of the peat of to-day and the coal of earlier periods has been formed. The mode of origin of coal will be discussed in Part III (Chapter XXI). A brief account will be here given of the formation of peat. Peat is partly decomposed vegetable matter. It is formed in cool climates in which the supply of moisture is plentiful and usually in swampy basins, although, as indicated above, deposits of peat are found on sloping grounds. Peat beds may be many feet in thickness, and the vegetable remains will be found most fully disintegrated at the lower levels, while near the surface the forms of twigs, leaves, and mosses are preserved in abundance. Peat is chiefly composed of water-loving plants, particularly of the genus *Sphagnum*, but may contain trunks and twigs of trees which grew on the spot and leaves and other matter drifted in by currents of air or water.

Peaty accumulations may extend from the shores over the waters of shallow ponds, thus forming quaking bogs. Masses of peat may also swell during rains and burst and overflow adjacent territory in a destructive manner. Not infrequently a deposit of peat overlies shell marl. The

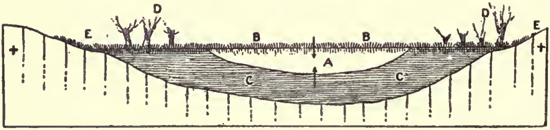



FIG. 82.—Growth of peat, with quaking bog. *A*, remnant of pond; *B, B*, living *Sphagnum*; *C, C*. peaty mass from disintegration of surface layer of plants; *D, D*, solid part of swamp with trees.—After SHALER.

marl was formed during the period of lake waters, the peat during the later swampy stage. Peat has antiseptic properties, and hence the bodies of men and animals are sometimes found preserved in bogs. Some such remains belong to prehistoric times, as utensils and canoes of the lake dwellers and skeletons of the extinct Irish elk.

Many peat beds are found in New England, including its bordering islands, and in Canada. In Europe they are found along the Loire and Somme in France, in Scandinavia and Scotland, and are of immense extent in Ireland, where from one tenth to one seventh of the country is estimated to be covered by them. One bog is reported to have an extent of nearly 240,000 acres and a depth of 25 feet.

152. **Other illustrations of the geological work of plants.**— Minute vegetable organisms called diatoms, living in lake and ocean waters and secreting small cases or shells of silica, are sometimes deposited in vast numbers, forming masses of so-called diatomaceous earth, a valuable abrasive material. Vegetable acids may precipitate silica from the water. Thus the woody fiber of some ancient trees has been replaced, as in the formation of the beautiful silicified woods of Arizona and South Dakota. Such acids also have

been instrumental in the accumulation of beds of iron ore. The iron scattered throughout certain rocks in minute particles is, by a series of chemical reactions, dissolved and brought together. Hence it is that coal and iron are sometimes found in proximity, as in Pennsylvania. The abundant vegetation furnished means of concentrating the iron, and the rocks are gray and comparatively colorless owing to the removal of the iron, to which rock colors are largely due. On the other hand, in the Connecticut Valley, where the color of the red sandstones is due to the disseminated iron oxides, no beds of iron ore are found.

### Geological Work of Marine Animals

153. Animals that live in water contribute to the history of the earth, chiefly in a constructive way, by the accumulation of their remains, often in masses of great extent and thickness. An exception to this rule is found in the case of boring mollusks, which perforate wood and even rock until it is sometimes honeycombed and destroyed.

The remains of sea shells and other hard parts of marine organisms accumulate in vast quantities on the sea bottom. Thus oysters and other mollusks occupy a tract of sea bottom, live and die, and leave their shells during successive generations. These shells consist mainly of carbonate of calcium which the living creature has secreted from its state of solution in sea water. If the water be shallow, as close to the shore, the shells will be worn and broken by the waves. With the entire or broken shells, and with fine mud arising from their grinding by the waves, is mingled sediment brought to the sea by streams. Thus limestones are formed, of great extent and thickness. For example, there are three great Paleozoic limestones in New York, each several hundred feet thick and stretching far across the State. We shall have further occasion to notice these organic accumulations in our study of rocks and when we come to review the history of the earth. Suffice it here to observe that most limestones of the earth's crust, including many marbles or modified limestones, are chiefly due to the presence in the sea of organisms ranging from most

Fig. 83.—Coral limestone bored by mollusks.

lowly up to the higher species. It is convenient under this head to refer to accumulations made by mollusks which inhabit fresh water. They are not geologically important, at least as regards bulk, but are common and of considerable interest.

Reference has been made to beds of shell marl which often underlie peat. In many lakes or ponds countless small mollusks with fragile white shells of calcium carbonate live and die, and their shells accumulate. The shells soon break up, and form a whitish fine ooze, which when dry is much like chalk. A rod may often be thrust many feet into such deposits of ooze, which have been gathering for centuries. It is such bottoms which lead to the tradition which one often hears in the country, that certain small lakes are bottomless. In time the water becomes shallow, vegetation encroaches upon the limits of the pond as already described, and the deposit ceases and is covered from view.

154. **Corals.**—These creatures are seldom seen by dwellers in the cooler zones, except as specimens in museums. Little but the hard parts of coral can thus be preserved, and hence much of their grace of form and most of their wonderful coloring are lost. Nevertheless, they have long had interest for students of natural history by reason of their beauty, their remoteness from most civilized regions, and their importance in world-making. Most erroneous notions have often been popularly held about them, as that they were "insects" and laid the foundations of their works in deepest seas. It is the part of geological study to give true views of this as of all agents which modify the crust of earth. This is the more true because of the importance of coral structures and accumulations in deciphering the history of the globe. They are rightfully regarded as indices of a warm climate, and therefore when found in the rocks of temperate or polar regions are demonstrative of great climatic changes. They are also important for the bulk of their contributions to the rocks of the earth's crust, insomuch that ancient formations are sometimes properly referred to as fossil coral reefs. Thus warm seas may be proved to have rolled their waves where now is found the interior of a continent. Some of the most famous names in the history of science also are identified with the study of corals. Here we think of Darwin and the voyage of the Beagle, Dana and the Wilkes Exploring Expedition, of the elder and the younger Agassiz, and other naturalists.

155. **Conditions of growth of corals.**—Corals are marine animals, and can not flourish in waters whose temperature falls below 68° F. The waters must be also comparatively clear and free from the muddy sediment which rivers bring from the lands. The species which are of importance in rock-making live within 15 or 20 fathoms of the surface.

This at once disposes of the fancy that they lay the foundations of islands in the abyssal depths of the ocean. Corals must also be exposed to the open surf; they do not flourish in quiet and protected waters.

Fig. 84.—Patch of corals on the Great Barrier Reef of Australia. (Saville Kent.)

156. **Distribution of corals in existing seas.**—It will be seen from the temperature limit as given above that corals can only thrive in tropical or subtropical seas. Thus they are widely distributed in the Pacific Ocean, in the torrid zone, and extend in some cases a few hundred miles beyond the tropics. Coral islands are low, and are thus distinguished from the high or volcanic islands of the ocean. They are very abundant—nearly three hundred in number, according to Dana, besides many reefs about other islands. Corals are not abundant on the American side of the Pacific, owing to the currents of colder waters which prevail.

Coral formations are found as reefs near certain islands of the Hawaiian group as far north as 28° 39′. Their limits south of the equator are narrower. Important coral masses are found in the Indian Ocean and up to 30° north latitude in the Red Sea, whose waters are very warm. Abundant reefs occur in the West Indies and off the coast of Florida. According to Le Conte, Key West owes its existence to the business of wreckage incident to the perils of navigation due to coral reefs. The Bermudas are the most northerly group of coral islands, reaching to 32° 15′.

157. **Coral reefs and coral rocks.**—The coral reef consists of a mass of coral *débris* which nearly or quite attains the surface of the sea. Part of the so-called reef is thus submerged, and bears a forest or garden of living corals whose petaloid forms and brilliant colors suggest a luxuriant growth of flowers. Other areas are raised above the surface of the sea as islands. The corals are often broken up by the waves, and so piled by the surf as to stand out of the water precisely as the fragments of common rocks may do. Such sands may then be attacked by the winds and built into still higher structures, as we have already learned in the case of the Bermudas. We may now look more closely at the origin of coral rocks. They are limestones, because the hard parts of the reef-building corals are composed of carbonate of calcium. The corals grow in a variety of forms, some hemispherical and massive, others branching and treelike, and often most delicate and fragile. The latter forms are readily broken by the waves, and the resistant masses are buried by the fragments of the others, by the broken shells of mollusks, and by the mud produced by the grinding of the surf mill or drifted from neighboring shores. Thus coral sands, coral in place, and miscellaneous materials unite and are at length consolidated in ways to be hereafter explained, and we may find a compact rock which rings under the hammer and from which, by

subsequent interior changes, much of the coral structure may have been lost.

158. **Kinds of coral reefs.**—They are of three sorts: (1) Fringing reefs. Along the shore of any island or other land where conditions favor, corals may grow. Thus a

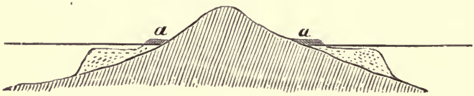



FIG. 85.—Section of island with fringing reef, *a*, *a*.

fringing reef is formed whose inner margin is composed of a belt of materials which have become subaërial through wind and waves. Its outer margin consists of submerged coral rock and living corals, extending down to the limit of depth. The land thus bordered may be of volcanic or other origin. (2) Barrier reefs. These lie at a greater or less distance from a shore, with which they are roughly parallel. The nearly inclosed areas of protected water are called lagoons. The reefs are often interrupted opposite streams, whose earthy load and fresh water are unfavorable to the corals. The great barrier reef of the east coast of Australia is 1,250 miles long, and is from 10 to 90 miles away from the mainland. (3) Atolls. An atoll is an elongated or irregular belt of low coral islands nearly inclosing

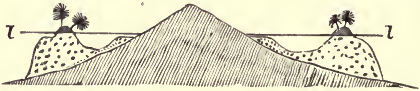



FIG. 86.—Section of island with lagoons and barrier reefs. Slopes much exaggerated.

a shallow central lagoon. The islands may be two or three or many in number, with a corresponding number of water channels leading from the lagoon into the open sea. Corals flourish but poorly in the quiet interior waters, but grow chiefly on the outside, where, below their limit, the sea bottoms may descend to profound depths.

159. **Origins of barriers and atolls.**—It was formerly supposed that atolls were the coral-covered rims of submerged volcanic craters. While volcanic islands are numerous, it is incredible that the summits of several hundred sub-

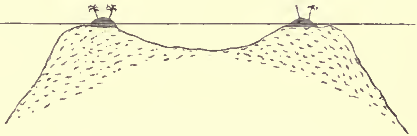


FIG. 87.—Section of atoll with central lagoon.

merged cones should be at the right horizon to support coral growth. Darwin propounded the subsidence theory, which was generally accepted, and still holds an important but disputed place. A brief statement is as follows: If a fringing reef borders an island which rests on a sinking sea

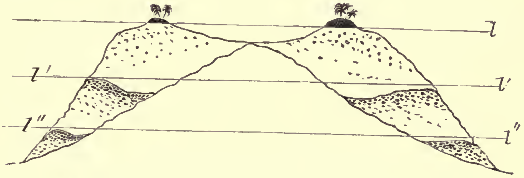



FIG. 88.—Diagram illustrating the subsidence theory of coral reefs. $l''$, $l'$ and $l$ represent sea level, which, for convenience, is shown as rising.

bottom, the growth of the coral mass upward may keep pace with the subsidence. As the corals flourish best in the outer surf, the accumulation will grow upward at that point, leaving a depression and growing lagoon behind. If the subsidence continues the original island will disappear, and we shall have a body of water nearly inclosed by a reef, or an atoll. All stages of this progress, according to Darwin and Dana, are seen among the coral islands and reefs of the Pacific Ocean. They thus regard as proved the subsidence of vast central Pacific areas during a long period of time. Agassiz, Murray, and others have, however, shown that some barriers and atolls have been formed without subsidence, particularly in the West Indies. The foundation on which the corals work must be within 150 feet of the surface, since the corals only thrive in comparatively shallow water. It is claimed, and with truth, that volcanic cones may be cut off by the waves just below sea level, and it has also been shown that in some cases shoals of sedimentary origin have been occupied by corals. It is claimed that the lagoons associated with atolls and barrier reefs, which are so readily accounted for by the subsidence theory, may also be explained in another way. Behind the belt exposed to the surf the corals do not flourish, and such coral structures as are formed in these more protected waters are, it is held, gradually dissolved and the carbonate of lime swept out, leaving basins of quiet water. Those who desire a fuller account of the several theories are referred to larger text-books, and to the special works of the authors cited above. A brief statement is at least useful in showing that there are important problems in the science of the earth which have been but partly, if in any measure, solved. We know many facts and some laws of Nature. That the deepest and largest questions await their answer is not a misfortune, but a high incentive.

160. **Age and rate of growth of corals.**—Few facts of observation are available. We know, however, that the growth is slow, and that any considerable coral accumulations must far outrun historic time. One authority, referring to coral communities of 6 to 9 feet diameter in the Red Sea, thinks that they might have been seen by the Pharaohs. At least corals illustrate the value of causes which operate silently throughout long periods, and they

also show in a remarkable degree the ability of frail organisms to flourish under, and indeed by means of, the powerful attack of the waves.

161. **How a reef becomes inhabited.**—After an island is thus formed by organic and physical agencies, it may receive the germs of land life in a variety of ways. Seeds of trees and other plants may be drifted upon the waters, or blown by the winds from neighboring lands. Others may be carried in the crops of birds, and in later ages life of various kinds has migrated by the hand of man.

## Geological Work of Land Animals

162. **Burrowing animals.**—Such are some species of mole, the muskrat, woodchuck, and prairie dog among the vertebrates. Their borings and tunnelings stir the soil, and particularly are effective in bringing up the subsoils to a horizon at which they may be made suitable for vegetable growth. The geologist is not infrequently aided by these creatures, especially in his study of the drift deposits. The crayfish also, of the class of crustaceans, sometimes perforates the levees of the Mississippi to such an extent as to cause a break in the barrier and flooding of the lowlands. The most widespread and important operations are carried on by the common earthworm, as shown by Darwin's observations. Soil and drift to the depth of several feet are perforated by these animals, which pass much of the material through their digestive tracts, where it is ground or dissolved and fitted thus for the use of plants. No inconsiderable quantity of such earth is cast by them upon the surface, so that Darwin estimates a gain of 1 to 1½ inches over the general surface in ten years. To this cause he attributes the disappearance by burial of stones in fields, and the covering of old foundations and pavements. All such subsoiling and transport to the surface favor general erosion by rains and winds, and are of course important in an agricultural way. The worms are larger and do more

work in some moist tropical regions, where lawns are sometimes rolled to crush the worm castings.

163. **Beavers.**—The beavers build dams often several feet high and many rods in length, and thus in some cases flood hundreds of acres of low-lying land, or cause it to become marshy. They also may interrupt drainage by felling trees thickly over an area. Thus vegetation of an aquatic sort is favored, and beds of peat may be formed. A history of Orleans County, New York, records that flooding by beavers was extensive there in the time of the pioneers, one beaver pond covering 100 acres or more. Works of an engineering sort have been performed by them, such as the


Fig. 89.—Aspens felled by beavers, Colorado.

cutting of water channels of considerable length for the transport of wood for their dams.

164. **Guano and phosphatic rocks.**—Guano is composed largely of the excrement, bones, and other remains of birds, and to some extent of other animals. Such deposits occur in dry climates, where the materials are not removed by leaching. They are found in Peru and other rainless regions. The places of deposit are breeding and cemetery grounds for these creatures, and were brought to notice by Humboldt in 1804 and by Liebig in 1840. Some ancient phosphatic lime rocks of great commercial value have been formed by the leaching of such deposits of guano, which rested upon the beds of calcium carbonate.

## Geological Work of Man

165. Without man the geological forces would seem to be aimless. With man they assume a high dramatic interest. But we must not here forget that man himself, the highest of land animals, is also a geological force of prime importance, able to subdue the earth, to control and direct in a large measure its manifestations of energy, and at length profoundly to modify its character. It is not easy to classify the body of facts to which we now refer. They form a network and are so intimately related and delicately balanced that to modify at one point may introduce a long series of changes. We may for convenience take the following heads:

166. **Planting and destruction of trees.**—The first act of man in a new country, if it be covered with forest, is to cut away trees and clear the land for tillage. He may carry this so far as to impair the spongy, shaded reservoirs of the rain which forest grounds afford, and deluge the lower lands with floods. The climate may be modified in ways not yet well understood, and the conditions of vegetable and animal life be revolutionized. On the other hand, man turns his attention to the foresting of prairies and to

the growth of trees on cold and barren slopes and on hill tops which ought never to have been denuded of their forest cover.

167. **Exposure by agricultural processes.**—The plow and harrow destroy the protective coat of plants and continually pulverize the soil and enable rivulets and winds to sweep it away. A blinding storm of fine earth may be raised over a plowed field while all the surrounding air is clear. The creep of soils by frost and gravitation is thus made easy, and the sidehill plow and other implements give the soils a direct push toward the valley bottoms.

168. **Excavations and borings.**—The opening of wells affects springs whose normal issue is at other points, and the piercing of reservoirs of gas may relieve stupendous pressures which would tend to work changes in the subterranean rocks. Innumerable quarries and railway cuts are opened, by which rocks are removed, and sections are made which vie with natural rock exposures in their value for geological study. Such are the Hoosac Tunnel, 4 miles long, and the wonderful St. Gothard Tunnel, which pierces the Alps for a distance of 9 miles. Even more extensive in certain areas are mining excavations, which may extend to the depth of a mile, and by which much of the rock under many acres of surface may be removed. Such a case is afforded by the city of Scranton, Pa. Earth movements and dangerous subsidences sometimes occur in this manner.

169. **Modifications of the flow of water.**—Some of the reservoirs and feeders of the Erie Canal on the high ground of the central New York plateau have served to turn the drainage of many square miles from the Susquehanna to the Mohawk basin. The building of milldams floods many tracts of low ground and has been a most fruitful source of legal actions. Raceways are cut, river channels are deepened and straightened or even diverted from their natural courses. Thus a stream in the Bernese district of

Switzerland was, in 1714, turned by a tunnel into Lake Thun, whereas it had entered the Aar at a considerable distance below the lake. The roof of the tunnel soon fell in, and the river now passes through an imposing gorge at that point and has built delta lands several acres in extent into the lake. It is of additional interest to note that the hand of man has but recalled the stream to its old course in preglacial times. Everywhere in Switzerland, as along the Rhone and down the slopes of innumerable alluvial cones, the rivers and torrents are "rectified" and kept by retaining walls from devastating adjacent homes and fields. The levees and jetties of the Mississippi River offer a further significant illustration of the geological activity of man. Even more striking, perhaps, is the Chicago Drainage Canal. For a distance of 28 miles a broad channel 40 feet deep has been cut, partly through drift and partly through the solid rock. By this means it is possible to divert a considerable quantity of Lake Michigan waters from the St. Lawrence to the Mississippi. This is also interesting as a partial return at least to glacial conditions of drainage. A great aggregate of artificial drainage has also been effected for agricultural and for sanitary purposes. Over hundreds of thousands of acres the flow of waters toward the sea is hastened. Thus vegetation is much modified, and, as stated by Coulter, the plants which man desires flourish, but many others suffer or disappear. A further diversion of natural flow is found in the irrigation so extensively practiced in dry regions. A dam is now under construction at the cataract of the Nile, by which a great body of water will be kept in reserve for the irrigation of lower Egypt. This may affect the climate and revolutionize the agriculture, and perhaps indeed the entire social and political development of the country. In California a million or more acres of land are "under the ditch"—that is, subject to irrigation—and about the same area in Colorado.

170. **Changes made by man on the seashore.**—On all civilized shores man co-operates extensively with the sea in its activity, as in the great variety of harbor constructions, preservation of dune surfaces, and the reclaiming of the salt marshes. For generations Englishmen have set themselves to reclaim the fens of Lincolnshire, and 400,000 acres of fertile fields and many thriving towns testify to their success; nearly 1,000,000 acres have thus been recovered in the Netherlands. Even to deep-sea deposits man makes his unfailing contribution, melancholy in interest, if insignificant in quantity. We have hinted at the widespread influence of man upon the surface materials and life of the globe. A fuller discussion belongs to Physical Geography.

## Summary View of Geological Forces

171. We have now passed in review the various ways in which energy is applied in changing the face of the earth. The atmosphere spreads everywhere, doing its destructive work. The distribution of water is almost as general, even on the land and beneath the surface. Glaciers either are or have been the means of change over immense areas. No part of land or sea is without some organic population, and volcanic and earth movements are the product of forces which never rest. Of the uncounted illustrations of all these processes we have here recorded a few, but others may be found by the student in whatever part of the world he chances to be; and nothing will make geological changes seem so real as to search them out and see them going on under our own eyes. These forces are sometimes classified as aqueous, igneous, and organic. While such groups partly correspond to the facts, we need not put stress on them, for even the aqueous agents wholly depend on heat for their efficiency. It is indeed the sun's heat, rather than the interior heat of the earth, but it is heat, and without it evaporation and the subsequent processes of aqueous erosion could not take place. So also igneous work mingles

with that of water, as in the explosive eruptions of volcanoes, in hot springs, and the consolidation of volcanic ash. Organic work also stands in a way by itself, but more truly considered is dependent upon heat and water for its effectiveness. Thus such definitions involve error and are at least incomplete. We might with some writers speak of surface and subterranean forces, but here again we come into confusion, as, for example, when we learn that the moon or atmospheric pressures have more or less to do with earthquakes. Perhaps it is better, as in the foregoing pages, to single out a few great kinds of agents, such as streams, glaciers, the ocean, volcanoes, etc., each doing a variety of things and all combining with each other in numberless ways, both in working and in results. Thus we go over the whole amid seeming confusion, but at length come out with a true appreciation of the orderly workings of a multitude of apparently diverse causes toward the harmony of the world and its fitness for intelligent beings.

The incessant movement of materials on the surface of the globe is one of the lessons which the student has learned. This is an important preparation for the later study of geological history, in which we must trace the course of changes during inconceivable periods of past time. One great law of such changes it will be profitable for us at once to appreciate—namely, the relation that holds between uplift and degradation. Elevation and denudation go hand in hand, and balance each other in a remarkable manner. If the lands are raised to a great height, either by oscillation or by folding, all the processes of denudation become at once powerful. Streams flow more rapidly, frosts are more constant and effective, glaciers form, and in some cases volcanoes may be an accompaniment of elevation. As the height of the land is reduced the erosive agents lose power, and moderate altitudes result. Thus an equilibrium is maintained between the forces of degradation and uplift. If continents were very high, they would be too cold and the air too rarefied for organic life. If they were too low, there would be no variety of environment, little beauty of scenery, little difference in organic groups, and a small degree of individuality among the nations of the earth. It has been well said that the highest progress goes with a diversified physical geography; such geography is the product of the network of geological forces, acting from the earliest ages of our planet's history.

# PART II
# STRUCTURAL GEOLOGY

## CHAPTER XI

### THE ROCK-FORMING MINERALS

172. **Introductory statement.**—We now turn our attention to the constitution of the earth's crust. We must learn something of the chemical and mineral composition of its rocks, and something of the forms, small and great, which these rocks assume. In Part I we studied the geological energies, with some reference to the resulting forms. Here we examine chiefly the forms, looking back incidentally to the forces concerned in making them.

We shall pursue our way from the smaller to the greater elements of the earth's structure. All matter consists, so far as we know, of certain elementary substances. Out of the elements minerals are formed, and these in turn are combined to make rocks. Rocks are of various kinds, according to the minerals that form them and the forces that affect them.

### The Rock-forming Minerals

While the number of minerals is very great, a small number compose the bulk of the rocks of the earth's crust. It is with these that we are chiefly concerned in the elementary study of geology.

173. **Chemical or unresolved elements.**—Of these, about 70 are thus far known to chemistry. More than 97 per

cent of the earth's crust consists of 9 of these. Of the 9, 3 are non-metallic—oxygen, silicon, and carbon. Oxygen is the most abundant of all, making 21 per cent of the atmosphere, 88.89 per cent of water, and 50 per cent of the rocks—that is, of such as are open to observation. Silicon comes next, forming one fourth of the weight of the earth's crust. The other 6, which are the most important metals from the geological point of view, are aluminum, calcium, magnesium, potassium, sodium, and iron. The following elements have in general minor importance, but in certain conditions or combinations become noteworthy —sulphur, hydrogen, chlorine, phosphorus, fluorine, manganese, and barium. Thus sulphur and hydrogen are frequent products of volcanic action, and sulphur, like carbon, is peculiar in sometimes forming rock masses without much admixture of other materials. Chlorine has interest as helping to form common salt, which in turn occurs as rock beds and is abundant in sea water. Phosphorus has economic value in rocks of limited extent.

174. **Definition.**—A mineral is matter which has a definite chemical composition, and commonly a specific geometrical form. Thus quartz and calcite are common minerals which possess both these properties.

175. **Properties of minerals.**—Minerals are described and identified by virtue of certain qualities which they possess. Many of these a mineral shares in common with others, but each has its unique aggregate of characters. The chief distinctions of this nature are the following:

(1) *Composition.*—This has to do with the elements which make up the mineral. We may make a definite analysis of it, or may use terms which express its chief character, such as metallic, non-metallic, hydrated, siliceous, carbonaceous, etc.

(2) *Crystalline form.*—Most minerals have this property, which means that they are bounded by plane surfaces of various form and arrangement. There are six chief kinds

of arrangement, called systems. The science which deals with them is termed crystallography.

(3) *Hardness.*—There are all degrees of this property, and ten well-known minerals have been agreed upon as forming a standard scale with which all others may be compared. Of the ten, No. 1 is very soft and No. 10 is the hardest mineral known. The scale is as follows:

| | | | |
|---|---|---|---|
| 1. Talc. | 4. Fluorite. | 7. Quartz. | 9. Corundum. |
| 2. Gypsum. | 5. Apatite. | 8. Topaz. | 10. Diamond. |
| 3. Calcite. | 6. Orthoclase (feldspar). | | |

Of these minerals, a piece of gypsum will scratch talc, but in turn is scratched by calcite. Any other mineral of which the same is true is said to have a hardness of 2. If hardness falls between two numbers—as, for example, a mineral which scratches orthoclase but is scratched by quartz—its hardness is said to be between 6 and 7.

(4) *Luster.*—Certain minerals are said to be metallic in appearance, vitreous or glassy, pearly or silky, as the case may be.

(5) Specific gravity.

(6) *Cleavage.*—The property of splitting along one or more planes. Calcite cleaves in three directions, feldspar in two, mica in one, while quartz does not possess this property. Cleavage is often more perfect in one plane than in others, and the cleavage planes, when two or more, like the crystalline faces, intersect each other at a definite angle for the given mineral.

(7) *Streak.*—This refers to the color of the mineral when reduced to powder, and is commonly learned by scratching the surface with a hard point, as of a steel blade, or by rubbing the mineral on rough porcelain.

(8) Properties depending on heat; as fusibility.

(9) Properties depending on the senses; as taste, smell, feeling.

176. **Mineralogy.**—The discussion of the properties and classification of minerals belongs to the science of mineral-

ogy, which is inclusive of crystallography. We here have place but for a short account of—

177. **The principal rock-forming minerals.**—These are silica and the silicates, the carbonates and other carbonaceous minerals, gypsum, chloride of sodium (common salt), and the iron compounds. These are the only minerals which form great masses of rock, though others may have economic value or scientific interest.

178. **Silica.**—Silica is the only known oxide of silicon, and in its most common form is called quartz. It takes the form of hexagonal crystals or is massive and ranks 7 in the scale of hardness, being the hardest mineral with which the student will commonly meet in the field. It can usually be recognized by one's inability to scratch it with the point of a knife blade. It has no cleavage, and when pure is transparent, being then known as rock crystal. It is insoluble in water and in most acids, but subterranean conditions are such as to have caused its solution extensively. Thus many fossils and mineral veins consist largely of quartz. Much quartz is milky in appearance, and the presence of various elements forms amethyst, rose quartz, cairngorm, and other varieties. Ferruginous quartz is dark in color, owing to the presence of iron. Dark, massive quartz is often known as flint or chert. Quartz is a most important constituent of rocks, as of granites, sandstones, and many others.

179. **Silicates.**—These minerals are of great variety and importance, particularly in igneous rocks. They are formed by the union of silica with a metal or base. Among the principal rock-forming silicates we have—

(1) *The feldspars.*—These are composed of silica and alumina with potassium, calcium, or sodium. Some feldspars cleave along planes vertical to each other, and hence are called orthoclase. Their alkali is potash. Many feldspars show oblique cleavage, and are termed plagioclase. Their alkalies are soda and lime. The hardness is 6, and

the colors are variable, though not pronounced. White, gray, green, yellow, and light red are among those that occur. Sometimes conspicuous crystals appear in a ground mass of other minerals. Feldspars decompose somewhat readily under the various influences of the atmosphere, and many clays, more or less pure, remain after the more soluble alkalies have been removed.

(2) *The micas.*—These are chiefly composed of silica, alumina, potash, iron oxide, and water. Their most conspicuous property is their cleavage into very thin leaves, which are nearly transparent. Micas have a brilliant luster and a hardness between 2 and 3. They occur as small flakes in many rocks, and sometimes in large crystals, affording broad sheets. Muscovite is the variety which is known in the arts. Granite, gneiss, and mica schist contain much mica, and sands formed by the breaking down of such rocks often shine with its flakes. It may be white, black, yellow, green, or brown.

(3) *Hornblende.*—This silicate contains alumina, magnesia, lime, and iron oxide. Its hardness is between 5 and 6, and its color may be black, dark green, or white. It occurs in prismatic crystals and in slender radiating crystals as actinolite, and is found fibrous in asbestos, which has become useful in the arts by virtue of this quality.

(4) *Talc, serpentine, chlorite.*—These are silicates of magnesia which also contain water. In taking up water they have been altered in composition, losing some substances and taking up others. They are soft minerals, readily cut with a knife, and are commonly greenish in color, with variations to white, red, or yellow, giving a mottled effect, and thus making some of them useful for ornamental work, as serpentine. Verd-antique marble is a mixture of serpentine and limestone. Talc varies from apple green to white, is greasy to the touch, and occurs as foliated and massive. Massive talc is steatite or soapstone.

180. **Carbonates.**—These are formed by the union of carbon dioxide with a base. The most important of these is calcite or carbonate of lime, which is the principal substance of all limestones, and enters largely into the structure of marine creatures. It thus forms a great number of the fossils which are preserved in rock strata. It is an essential element of soils, and vast amounts of it are in solution in the sea. It is 3 in the scale of hardness, and may thus always be easily distinguished from quartz, which in appearance sometimes resembles it. It is more commonly colorless or white, but may be red, gray, yellow, or black. It effervesces vigorously with cold dilute hydrochloric acid, and may thus be detected when scattered in small quantities in rocks other than limestone.

Dolomite is a carbonate of calcium with magnesium. Dana gives the proportions thus: calcium carbonate 54.4, magnesium carbonate 45.6 = 100. Dolomite looks like calcite, but does not effervesce with cold dilute acid. Massive dolomite forms rocks of considerable extent, and is often called magnesian limestone. Some dolomites form hydraulic cement.

181. **Other carbonaceous minerals.**—Chief among these are the varieties of coal and mineral oil.

*Coal.*—This substance is the product of vegetable accumulations in different periods of the earth's history. The least changed member of the series is peat, of which an account has already been given. The next is lignite, sometimes incorrectly called "brown coal," which retains much of its woody structure. Bituminous coal exhibits a cubical fracture, burns with much flame and smoke, and contains 65 to 85 per cent of carbon. Anthracite coal is hard and lustrous, burns with little flame, and commonly contains 90 to 95 per cent of carbon. Graphite (black lead) is properly included here, as having passed a stage beyond anthracite in the loss of its volatile materials. Like the diamond, graphite is pure carbon, though the two differ so much in appearance. More generally graphite and anthracite are found among the older rocks, and bituminous and lignitic coals always occur in strata of moderate geological antiquity.

Cannel coal is dense, lusterless, breaks unevenly, and burns with a bright flame. Little or no trace of plant structure remains in it.

The coals might with some propriety be described as rocks rather than as minerals, since their chemical composition is variable, and they thus fall short of the definition given.

182. **Sulphates.**—The only important rock-forming compound of sulphur is gypsum. It contains about 20 per cent of water. When pure, it is often crystallized, and is known as selenite. It is frequently transparent, pearly in luster, and cleaves into thin leaves. Sometimes it is fibrous, and is called satin spar. It is often massive, and is ground for use as a fertilizer. White and pure massive gypsum is alabaster. If the water be driven off by heating and the residue reduced to powder, it is called plaster of Paris. Gypsum is often associated with beds of rock salt.

183. **Chloride of sodium (common salt).**—This mineral has great economical value, and was formerly derived mainly from sea water. In modern times, however, large beds of it have been found associated with the stratified rocks of various countries.

184. **Iron compounds.**—Those which are important geologically are four in number:

(1) *Magnetite.*—It is black, either crystalline or massive, magnetic, and is an important iron ore. It is composed of iron, 72.4 per cent; oxygen, 27.6. The streak is black. Particles may frequently be withdrawn by a magnet from seashore or glacial sand.

(2) *Hematite.*—Occurs as crystalline, or massive and earthy; forms a red powder. Red ochre is the earthy variety. It contains iron, 70 per cent; oxygen, 30 per cent.

(3) *Limonite.*—This is a brownish or yellowish ore, containing iron, oxygen, and about 15 per cent of water. The yellow sort is yellow ochre. An impure earthy variety of limonite is found in swamps, and hence called bog iron ore.

(4) *Pyrites.*—Magnetite, hematite, and limonite are oxides of iron, but pyrites is a sulphide. It contains iron, 46.7 per cent; sulphur, 53.3 per cent. Occurs massive and in cubical crystals, is pale or bronze yellow in color, and widely distributed. It has often been taken for silver, gold, or copper. It has little value, is not used for making iron, but is sometimes employed for the manufacture of oil of vitriol or sulphuric acid. Occasionally it contains enough gold to pay for working.

# CHAPTER XII

## COMPOSITION AND MINUTE STRUCTURE OF ROCKS

185. HAVING passed in review some of the more important minerals, we now turn to the rocks which they form. In a few cases a single mineral occurs in large masses, and may be called a rock; but most rocks are a mixture of two or more minerals. Often two or three characteristic minerals make up the bulk of a rock, while a large number of others are present in small quantities. The minerals in rocks may be perfect crystals, but more often occur as crystalline fragments, or in such minute particles as to require chemical tests or microscopic observations for their detection. The science which thus deals with the making up of rocks is petrography. It is a department of geology, and this chapter will present a few of the more simple and common facts. Rocks may be classified as fragmental, igneous, and metamorphic. Before taking these up it will be well to define a number of terms used to describe the appearance and character of rocks.

186. **Descriptive terms.**—A rock is crystalline if composed of whole or partial crystals, whose lustrous faces often shine on the wall of a fracture. The adjectives compact, amorphous, and massive are sometimes loosely used. Properly, *amorphous* refers to the absence of the crystalline condition, *massive* to the absence of large planes of division, especially planes of stratification, and the particles of a *compact* rock are not seen by the unaided eye. A friable rock crumbles readily, as under the pressure of the fingers.

*Granular* rocks are composed of nearly equal grains of one or more minerals, and *vitreous* refers to a glassy appearance. A *shaly* rock splits readily into thin, smooth layers along planes of stratification. *Foliated* or *schistose* rocks also split readily, usually into wavy layers, because of leaves or scales of a cleavable mineral like mica.* *Cellular* describes a rock with small rounded cavities, such as bubbles of air or gas cause in lava. If complete crystals of one mineral appear imbedded in a ground mass or matrix of others, the rock is *porphyritic.* If a rock is made up of small rounded grains like the roe of fish, it is *oölitic.* If the grains have the size of peas, the rock is called *pisolitic.*

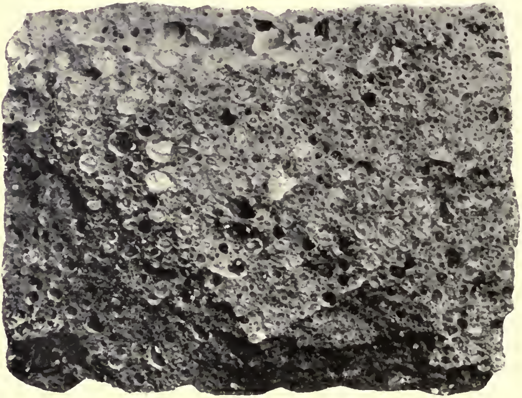


Fig. 90.—Cellular structure.

Various terms scarcely needing definition refer to a more abundant or characteristic element in the composition of rocks. Thus calcareous rocks have a considerable proportion of lime; argillaceous rocks contain much silicate of alumina or clay; ferruginous rocks are so called

* See, on the schistose rocks, p. 213. For the distinction between schistose structure and slaty cleavage, see p. 241.

from the presence of iron. Similarly we use the words siliceous, quartzose, saliferous (salt-bearing), micaceous, and carbonaceous. Likewise the whole series of color

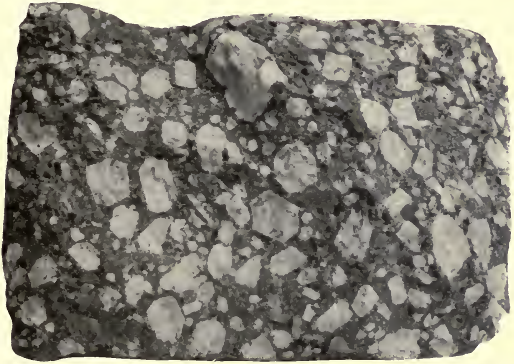


FIG. 91.—Porphyritic structure.

terms is needed in the study of rocks. White, black, and many shades of yellow, brown, red, blue, and green are found. A true eye for color is desirable for one who would go far in the study of rocks or be able to describe them.

### THE FRAGMENTAL ROCKS

187. These rocks are so called because they consist of fragments, usually small but sometimes large, of older rocks. They are commonly deposited in water, and hence are often called sedimentary or aqueous. They may be laid down in the bed of the sea or of a lake, or along the course of streams. Masses of talus or of volcanic ash unmodified by water are examples of non-sedimentary fragmental rocks. This class of rocks may have any chemical constitution, depending upon the character of the masses from which they were derived. We take first—

### 1. *The Sand and Gravel Group*

188. **Sand.**—This consists of broken particles of rock of any kind. The fragments are of appreciable size, but not larger than is expressed by the term grain. More commonly most of the grains are of quartz, because this mineral is hard and survives the wear of waves and currents. Even if sands show various colors, a low-power microscope will reveal a surprising predominance of the quartz. The grains will also be angular or rounded and battered, according to the distance traveled or the violence of the waves to which they have been subjected. We distinguish river sand, beach sand, whether of lakes or ocean, eolian sand, which mainly is derived from beaches, glacial sand, and volcanic sand.

FIG. 92.—Conglomerate.

*Sandstone.*—A sandstone is a mass of sand whose grains are more or less firmly bound together by some kind of cement. Frequently the cement is an oxide of iron, giving a red color to the rock. Sometimes the cement is a deposit of quartz among the original quartz grains, forming a most durable rock. Other sands are cemented by carbonate of lime. Even recent glacial sands are sometimes changed into firm rock by infiltration of lime waters. This cement being soluble, calcareous sandstones are less durable.

*Gravel.*—This name is given to a mass of pebbles or of coarse sand mingled with pebbles. Beds of gravel often alternate with beds of sand and beds of clay, pointing back to alternating seasons, or wet and dry periods, with swift and sluggish flow of currents; or, in the case of the sea, the gravel may lie on the upper margin of the beach and the sand below.

*Conglomerate.*—Thus we designate the rock formed by the consolidation of gravel by cementing and pressure. If the pebbles are rounded by water action, the resulting conglomerate is sometimes called a pudding stone. Such is the Oneida conglomerate of central New York, the Lower Carboniferous conglomerate of "Rock City" near Olean, N. Y., or the very ancient Roxbury conglomerate in Boston.

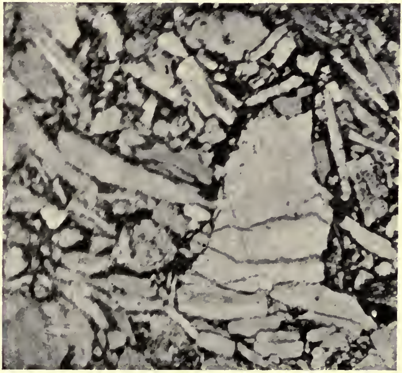


FIG. 93.—Limestone breccia, near Highgate Falls, Vt.

*Breccia.*—A breccia is a rock formed by consolidating a mass of angular rock fragments. Thus we may have talus, volcanic, and fault breccias, according to the mode of origin of the fragments. In the last case the fragments are formed by the crushing that sometimes takes place during movements of dislocation along a fracture plane. Such rocks sometimes cut and polish well, and the angular pieces show finely in ornamental work.

### 2. *The Clay Group*

189. True clay is a silicate of aluminum formed in great abundance by the decomposition of feldspathic rocks. It is fine, smooth, plastic, and of various colors, depending upon slight admixtures of other substances. The term clay is, however, loosely applied to a great variety of muds, consisting largely of finely pulverized rocks of many kinds, in which some true clay is usually present. Such are many clays of the sea bottom, formed of the finer land waste, the clays of ancient lake basins, now drained, and many clays of glacial origin. The last are often blue below, but yellow or reddish in their oxidized upper portions.

Kaolin is a pure, often white, oily-feeling clay, valuable for pottery. Brick clay is an impure variety, containing iron, to which, when oxidized in burning, the color of brick is often due. Fire clays are used for bricks when walls or inclosures are desired which will endure great heat. They are nearly free from lime, alkalies, and iron. A clay mingled with calcium carbonate forms marl. A loam consists of clay with sand and some vegetable matter, as in many of the best and most easily worked soils.

**Shale.**—A shale is a clay or mud rock which splits into thin leaves along the planes of deposition. These rocks show great diversity of composition, according as lime, iron, or other substances are present. They may contain fine sand, and thus grade into sandstones. Indeed, we may find a perfect series from the finest shales to the coarsest conglomerates. Some shales contain much carbonaceous matter, and are used, as in Scotland, New South Wales, and elsewhere, for the production of gas and oil. If the calcareous matter is abundant in shales, they grade into limestones, forming as perfect a transition as in the case of sandstones.

### 3. *The Limestone Group*

190. These rocks are mainly of organic origin, and often preserve a full record of the marine life of their period of deposit. The principal mineral in them is carbonate of lime, but many other substances enter into them, so that they are various in texture, hardness, and color. More commonly they are of dull blue, drab, or grayish hues, but sometimes they are black, not infrequently yellow, and occasionally white. They may hold much clayey material and thus graduate into shales. Carbonate of lime may mingle with sand, producing a rock of intermediate type.

Some limestones are crystalline, while others look like a hardened mud. The crystalline structure is usually due to changes during long periods following the time of formation. It may, however, develop more rapidly under the influence of pressure or heat. Limestones are sometimes shaly and of loose texture, and others are massive. When limestone is burned, carbon dioxide is driven off, leaving quicklime. Some limestones, when freshly broken, give off strong odors, due to the presence and decomposition of organic matter.

Certain varieties of limestone should receive particular mention. One of these is chalk, a white, fine-grained, soft, and friable rock. The Cretaceous formation of England contains extensive and famous beds of chalk. Similar deposits are found in Texas, and resemble some of the beds of ooze in modern seas. A chalky accumulation known as shell marl, and occurring in fresh-water ponds, has already been described. Hydraulic limestone is so called because when ground it will "set" under water. It contains various impurities, such as silica, alumina, and sometimes iron. Travertine is a lime rock deposited from springs. It is sometimes called calcareous tufa, and is common on the banks of streams or springs that issue from limestone rocks. It frequently incrusts or forms molds of leaves, twigs, and other objects.

## The Igneous Rocks

191. **General characters.**—The igneous rocks are always unstratified, though they may lie between sedimentary beds, and thus have the appearance of stratification. They are never fossiliferous, though a lava stream or bed of ash might by accident include organic forms. They are sometimes called massive, but, as we have seen, this term is also used for water-laid rocks, whose bedding planes are infrequent and inconspicuous. Igneous rocks are also called crystalline, but some volcanic beds are not so, while some sedimentary rocks have this character. But all show signs of the action of heat, and the term igneous is therefore appropriate.

Ancient as some fragmental rocks are, many of the igneous masses are older, and constitute the floor on which the sediments rest. This basement formation would be found everywhere if our observations could go far enough into the crust of the earth. Igneous rocks also belong to all geological periods, and their age is determined by their relation to the fossil-bearing rocks with which they are associated.

192. **Classification.**—In a general way igneous rocks are classified according to the place of their formation. If they were formed in a deeply subterranean zone, they may be called Plutonic. If near or upon the surface they are volcanic or eruptive. But there are all gradations between the two. The Plutonic rocks are crystalline, for the reason that cooling proceeded slowly, and the elements had time to arrange themselves in crystalline forms before the mass became rigid. Such rocks now often lie at the surface. This means that prolonged erosion has stripped off the cover of overlying rocks under which they were formed. The granites, or at least many of them, belong to this class,

but are now extensively brought to light in all parts of the world. The volcanic rocks are crystalline in a much less degree, but often reveal the presence of minute rudimentary crystals under the microscope. Obsidian and basalt are examples.

Igneous rocks are also subject to chemical classification. The broad principle of arrangement is the presence of varying proportions of silica and metallic bases. If the proportion of silica is as high as 60 to 80 per cent, the rock is called acidic. Granite is an example of a Plutonic, acid rock. Obsidian is a volcanic acid rock. If the silica falls below 60 per cent and the metals are strongly present, the rock is called basic. Basalt is a common example of a basic rock. A complete series, however, unites the two sorts.

193. **Plutonic rocks.**—Among the most common and important is granite. It should be stated that some granites are thought to have been formed, not by the cooling of molten matter, but by extreme modification, or metamorphism (section 196), of sediments. The primary minerals in ordinary granite are three—quartz, feldspar, and mica. The quartz may be recognized by its glassy grains, which usually do not show a crystalline structure. The feldspar shows its crystalline faces, and is generally pink or gray or whitish in color. The mica may be detected in flakes of greater or less size, according as the rock is of fine texture or coarse. Other minerals are present in small degree. If hornblende occurs in place of mica, the rock is a hornblende granite. The color of granite varies much, particularly with the colors of the feldspar. Thus we may compare the familiar red Scotch granite, with the gray granites of Quincy or Cape Ann, Massachusetts. Granites are widely distributed, and often occur over large areas. Granite forms the core or axis of some mountain ranges, as in the Pyrenees, Himalayas, and Sierra Nevada. It also occurs as veins and in other forms intruded into rocks of different character.

194. Syenite is a rock whose chief constituents are feldspar and hornblende without quartz. It also contains a number of accessory minerals, and, like granite, has been formed in many periods of geological history. Hornblende granite was formerly called syenite. Diorite is chiefly composed of hornblende and plagioclase feldspar, differing from syenite in the character of its feldspar, which in the latter is orthoclase. Diorite is a fine-grained rock, and is not infrequently called greenstone. If the rock contains some quartz it is called quartz diorite. Gabbro and diabase are dark-colored rocks, of which plagioclase feldspars are always a constituent, resembling the basalts in composition, but more fully crystalline, being mainly of deep-seated or Plutonic origin. They are often called trap rock, and form (diabase) the Palisades of the Hudson, and occur extensively (gabbro) in the Adirondack Mountains. It is to be remembered that some of the Plutonic rocks are acid, like granite, while others, like the diabase and gabbro, are basic. Many other kinds of Plutonic rocks occur, with endless varieties of those here briefly described, but the knowledge of these belongs to Petrography.

195. **The volcanic or eruptive rocks.**—These also are both acid and basic. As before, we begin with an illustration of the more acid type, the obsidian or volcanic glass. It contains 70 per cent or more of silica, varies from green or blue to red, brown, or black in color, is more or less translucent, and breaks like bottle glass. It is an acid lava, so rapidly cooled that it contains only minute or rudimentary crystals. Sometimes it shows banding, preserving the flow structure of the lava. It may be cellular, and if largely so, becomes a volcanic pumice. It occurs, among other places, in Teneriffe, in Iceland, and forms Obsidian Cliff of the Yellowstone National Park.

Rhyolite and trachyte are "stony" lavas much like obsidian in chemical constitution, but having cooled more slowly, thus assuming a crystalline structure, though more or less of glass remains in which the crystals are imbedded, especially in the rhyolites. They occur in great abundance in the lava flows of later geological times in Europe and the western United States. The basalts include the more basic eruptive rocks. Typical basalt is a dark lava, whose crystals are microscopic, or are scattered, forming a porphyrite structure. Some basalts are glassy, and thus resemble obsidian in structure. If a basic lava has cooled slowly, so as to be coarsely crystalline, it is called a dolerite. The basalts usually contain 40 to 50 per cent of silica. They are widely distributed and form the lavas of many Tertiary and modern eruptions. They often assume a columnar structure (section 236).

## The Metamorphic Rocks

196. Metamorphism is literally a change of form, and comprehends certain changes in rocks, especially in the direction of hardness and crystalline character. It is not used of the ordinary degrees of pressure and cementation by which loose sediments are made to cohere, but of changes beyond these, often involving decided modification in the character and arrangement of the constituent minerals. Metamorphic rocks may be derived either from sedimentary or from igneous formations. Ordinary consolidated sediments may become quite hard and crystalline, and we thus pass insensibly to the true metamorphic types. Metamorphic aqueous rocks are commonly without fossils, but in some cases the changes have stopped short of their obliteration. Volatile matters are driven off, as when soft coal becomes anthracite.

197. **Where metamorphic rocks occur.**—They are found more often among the older rocks, but sometimes in those of recent origin. The ancient rocks have been subject to a very long series of modifying influences as compared with the modern. In regions of vulcanism, hot lavas have meta-

morphosed the rocks with which they came in contact. This takes place on the walls of dikes, and above and below intrusive sheets, or beneath a lava stream. The rock is baked, or modified by hot vapors or heated waters. Such effects can extend but a little way from the heated mass, and hence the result is called *local* metamorphism. But similar changes take place over many thousand square miles, and are due to more general causes, as we shall see. In this case we speak of *regional* metamorphism. Western New England and eastern New York, including Manhattan Island, form a great belt of metamorphic rocks. So we find them in parts of the Adirondacks, in northern Michigan, over great areas in Canada and in the Highlands of Scotland, in the English lake district, and in Wales. Local metamorphism is found in regions of recent or ancient volcanic action; regional metamorphism is found in areas of widespread disturbance and crushing.

198. **Sedimentary origin of some metamorphic rocks.**— That some metamorphic rocks were originally fragmental is shown in a variety of ways. Occasionally, though rarely, fossils are found in them. This is the case near Rutland, Vt., where fossils have been discovered in rocks lying between ranges of marble quarries, and in Bernardston, Mass., where a variety of metamorphic minerals is found closely associated with Devonian fossils. In Norway, also, a Silurian limestone contains at once fossils and crystals of garnet. The fossils show that the rock was once sea mud, while metamorphism has gone far enough to develop the garnets. In some metamorphic rocks the planes of bedding or stratification remain to show their origin. But the student must be on his guard in such observations, because planes of cleavage of later origin resemble bedding planes. A sheet of metamorphic rock, showing no trace of former fragmental condition, may lie between two beds of limestone. The limestones are presumably sediments, and the included mass is likely

to have been such. One of the best proofs of metamorphism is sometimes at hand: namely, to find the sheet of rock shading off into unmodified sediments as it is traced for some distance.

199. **Causes of metamorphism.**—There is considerable agreement as to the general agents which promote interior changes in the structure and constitution of rocks, but much remains to be known of the exact nature of the several processes, and of the way in which they interact among themselves. Thus it is known that heat greatly favors metamorphism. It can not be extreme measures of heat, for these would melt the rock, which might not then be readily distinguished from eruptives. According to Dana, 500° to 1,200° F. is heat sufficient for the work done, when taken in connection with other agents yet to be named. The heat may be derived in some measure from the earth's interior, but is more largely of dynamic origin. Hence it is that regions of crushing are regions also of metamorphism.

Moisture also hastens metamorphism. Especially when heated does it lessen the coherence of constituent particles and favor their rearrangement—that is, it aids in making the rock plastic. Much water is not needful. We have already learned that all rocks contain water. Dana shows that the average amount of water would furnish nearly 45 cubic feet of steam for each cubic foot of rock.

Pressure is another essential, or at least common agent, in metamorphism. Such pressures are mainly due to crushing movements of the earth's crust, though something is to be ascribed to the weight of overlying masses of rock. That the latter may not be enough, however, is shown by the fact that sediments once buried under many thousand feet of rocks and now brought to light by denudation, may not show metamorphism. It is also known that the presence of alkaline substances greatly hastens some metamorphic changes, as the solution of silica, which is hardly affected by water under ordinary conditions at the surface of the earth.

200. **Examples of metamorphic rocks.**—There are all grades of metamorphism, shading down into a simple consolidation of sediments, and perhaps extending, on the other hand, to complete melting. Thus some granites are believed not to be originally igneous, but to be the products of extreme metamorphism. Hence we may again see how difficult it is to classify the facts of Nature. We have learned that fragmental rocks may be the *débris* of igneous, metamorphic, or of older fragmental rocks. Metamorphic rocks may be modified sediments or modified igneous products, while igneous masses may be parts of the originally molten globe, or result from the melting of any and all other classes of rocks. Any particle of matter may, during the history of the globe, have gone through many such changes. We now turn to the principal metamorphic types.

(1) *Marble or metamorphosed limestone.*—Ordinary crystalline limestone which will take a good polish is sometimes called marble. But the true marble is composed of the crystalline, granular carbonate of lime. That it is a changed limestone is shown by its being sometimes associated with fossils. Geikie cites several places in which limestone was changed into granular marble next to a dike. These are cases of local metamorphism by heat. Chalk and lithographic limestone have been changed into marble artificially in the laboratory. The marbles found occupying a considerable area or belt, as in Vermont, are an illustration of regional metamorphism. Pure carbonate of lime forms white marbles, but other substances are often present, giving a variety of colors, as seen in the large number of ornamental marbles.

(2) *Slate.*—Shales and clayey rocks in general are metamorphosed into compact, hard slates. A mud rock which would break down under a winter's frost may thus be made resistant to the changes of many years. Such is the origin

of roofing slates and those of school use. These split with great facility out of the blocks which are lifted from the quarry. The planes, however, are planes of cleavage (section 231), while the original planes of deposit are usually obliterated. Roofing slates occur in various shades of blue, green, brown, and red. Other slaty rocks do not thus cleave, but are much divided by joints. The slates of Somerville and Braintree, Mass., are illustrations.

(3) *Quartzite.*—A sandstone composed mainly of quartz grains is changed by metamorphism into a compact quartzite. The change of texture is commonly due both to pressure and to the deposit of secondary silica among the sand grains. It thus becomes a very durable rock.

(4) *Gneiss.*—This is a banded or foliated rock, and the more common or typical gneiss has the same chief minerals as granite. Sometimes the bands are very perfectly developed, thin, and allow of easy splitting. In other gneisses the banding is coarse or obscure, and thus there is a gradation into the granite. In some cases this rock has its origin in the metamorphism of granite, while in others it is believed to be derived from a sedimentary mass, as sandstone. Gneiss is abundant among the pre-Paleozoic formations.

(5) *Other schistose rocks.*—A schist is a rock whose minerals are crystalline, and form leaves or layers along which splitting readily takes place. Gneiss, as above said, has this structure in greater or less degree. We may have a quartz schist in which enough scales of mica are present to give the rock a foliated character. With less quartz and more mica we have mica schist, common among the metamorphic rocks of western New England. It shines with scales of mica, splits easily, and readily disintegrates, filling with its bright spangles the sand which is produced. Garnet and other minerals occur as accessory. Other schists take names from minerals which are prominent in the composition; thus we have talc, chlorite, and hornblende schists.

(6) *Anthracite.*—This is derived by metamorphic processes from soft or bituminous coal. Thus the anthracite of Scranton and Wilkesbarre is of the same age as the soft coal of western Pennsylvania, Ohio, and Illinois, but has been subject to powerful compression in the mountain-building of the eastern region. Similarly all the coals of Colorado are soft, save in a single region of volcanic disturbance, where anthracite occurs. In harmony with these results, graphite, a still purer form of carbon, is found among very ancient and powerfully metamorphosed rocks, as in Canada.

The student should remember that we have described but a few examples of the rocks of the earth's crust. Their variety is infinite, and it is the work of a lifetime to know them. But it is also true that faithful study of the rocks themselves will soon give practical familiarity with the common rocks which we see in quarries, and in the various structures which man makes out of stone.

## CHAPTER XIII

### THE GROSS STRUCTURE OF ROCKS

201. THUS far we have studied rocks in their minute characters, of which some are plain to the unaided eye, while others reveal themselves by chemical tests or by the use of a microscope. We turn now to a series of larger structures. We begin with those which occur only or chiefly in sedimentary rocks, such as strata, folds, and unconformity. Then follow structures common to all rocks, of which joints, faults, and veins are examples. Finally, we come to certain forms and structures peculiar to igneous rocks, such as dikes, intrusive sheets, and volcanic necks. The composition and minute structure of rocks are related to gross structures somewhat as organic chemistry and histology are related to gross anatomy in the study of plants and animals.

### STRUCTURE OF SEDIMENTARY ROCKS

202. **Stratification.**—Sedimentary rocks are always deposited in more or less distinct layers, and are said to be stratified. This is the most important rock structure with which the geologist deals. A single layer is called a bed, and hence the sedimentary rocks are often called bedded. A succession of layers of the same kind is a stratum, which may be several or many feet thick. The term stratum is, however, very commonly used as synonymous with bed.

203. **Appearance of stratified rocks.**—If one visits a gravel or sand pit, he will commonly find beds of sand, or some-

times of fine mud alternating with layers of gravel, or variations of coarse and fine sand. The finer beds are deposited in gentle currents, or when wave action is moderate; the coarse beds when such movements are strong. It is the difference between storm and calm, floods and low water, rainy and dry periods. When we observe the walls of a quarry or natural ledge, we often find beds and division planes without such changes between coarse and fine materials. Not infrequently a thin layer of shale, or fine, consolidated, argillaceous mud separates the beds, as of limestone. Sometimes the division is determined by a thin layer of fossils, along whose plane the mass splits readily. Weathering always develops the bedding planes, so that in ledges or old quarries spaces as thick as one's hand may sometimes be found between layers. The similarity of texture of several beds of a thick stratum is due to their deposit in deep or quiet waters, where variations of velocity could not occur. The origin of bedding planes in such situations is not so clear. They may sometimes be due to fossils, as above stated, and sometimes to periods of non-deposition, during which partial consolidation of the last laid bed or of its upper surface takes place.

Beds are of variable thickness, from one or a few inches to several feet. In the latter case they are called massive. A bed often indicates, by a fine banding on its edge, many subordinate layers, which are called laminæ or leaves. Sometimes the rock splits freely on the planes of lamination, as in the fine paperlike shales of Florissant, Col. There is no sharp distinction between beds and laminæ.

204. **Position of stratified rocks.**—When undisturbed, this is commonly nearly horizontal, but not often exactly so. Such rocks are made on gently descending lake or sea bottoms, or along the slight incline of a river valley. The rocks of central and western New York generally dip southwestward or southward 25 to 50 feet per mile. They may

have inclined as much as that when first formed, though slight variations have doubtless been introduced by oscillations with warping. Taken as a whole, the beds of a pond or lake are saucer or platter shaped, and some central portions may thus be horizontal. Highly inclined but undisturbed beds are found in many aqueo-glacial deposits and some deltas.

205. **Vertical succession of strata.**—This may be shown on the sides of gorges or of mountains by deep borings, or more often by successive outcrop of slightly inclined beds across the face of the country. It is common for limestones, sandstones, and shales to succeed one another in various order. In one part of the New York series of rocks a sandstone 12 feet thick lies between two limestones. Above the upper limestone come fine black shales, and these are succeeded by a great alternation of sandstones and gritty shales. Sometimes the change from one kind of rock to the next is abrupt, but often it is gradual by passage beds of intermediate character.

206. **Horizontal extension of strata.**—Some strata extend for hundreds of miles, and single beds may be traced for considerable distances. But change of thickness and character generally accompanies such horizontal prolongation. Not infrequently a bed thins out in one or more directions, forming a wedge or a lenslike mass between others. Upon a little reflection the student will see that this is the form in which bodies of sediment must now be laid down in lakes and seas. The Niagara limestone, and some other formations which are important in western New York, thin down and nearly or quite disappear south of the Mohawk River. Sandstones are made alongshore, and fine muds in the deep waters. By such changes in ancient strata the place of shores and deep waters is often determined for former periods. It is by the study of present conditions that we may read the geography of land and sea in far-distant ages.

Fig. 94.—Cross bedding in coal measure sandstone, Redrock, Marion County, Ia. From Iowa Geological Survey.

207. **Cross bedding or false bedding.**—This is the term used when the laminæ of a bed are oblique to the general planes of stratification. Such beds are formed in shallow water, and therefore occur most often in sandstones. Small embankments are formed under water with a sloping front advancing with successive deposition, like a railway filling.

Fig. 95.—Limestone, showing cross bedding and columnar structure, near Catskill, N. Y.

208. **Ripple and rill marks.**—The former may be observed on almost any shallow bottoms where the waters are stirred by the wind. They may be covered by quiet later deposition and preserved. Perfect examples are thus found in the most ancient sedimentary formations. When the waves retire from a shelving sand beach, little rills of water flow down the incline and erode small channels in the sand. They may excavate pockets about an opposing pebble or

shell. Such structures are likewise found on the surface of layers of ancient sandstones.

FIG. 96.—Ripple marks on Triassic sandstone. Turner's Falls, Mass. Slab 43 by 24 inches, of which one half is here shown. Photograph by N. Y. State Museum.

209. **Rain prints and sun cracks.**—Let the water soak away from a roadside pool, and raindrops splash upon the soft surface mud. A roundish impression is made which may even show the direction in which the rain fell. Or the drying of the mud shrinks and cracks it into rough polygonal blocks. Let another rain ensue, and the fresh supply of mud will fill the cracks and cover the bottom of the pool anew, thus making a cast or mold of the cracked layer. Both this structure and the rain prints are sometimes found in splitting open beds of ancient rocks.

210. **Fossils.**—These are commonly small structures, sometimes harder, but often softer, than the rock which

holds them. In the latter case especially they are a source of weakness, and favor the disintegration of the mass. While not very important as physical structures save in

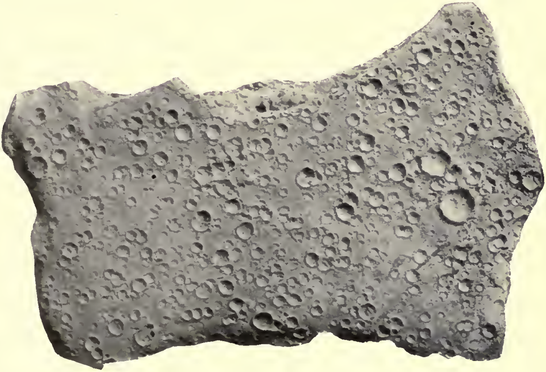


Fig. 97.—Recent rain prints.

Fig. 98.—Sandstone, showing ancient mud cracks, Portland, Conn. Photograph by W. H. C. Pynchon.

their contribution to the limestones of the world, they are of supreme importance in tracing the thread of the earth's history.

211. **Concretions** (from *con* and *crescere*, to grow together).—These are aggregates of some mineral lying often in a sedimentary bed of different character, as nodules of

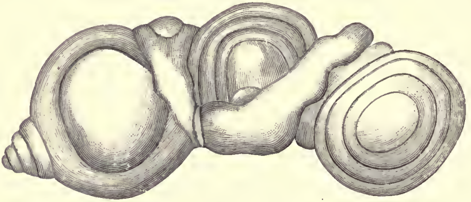


FIG. 99.—Concretion of fantastic form.—After GRATACAP.

flint in limestone. They may be spherical, or round and flattened, or elliptical, or of irregular and fantastic forms. By the inexperienced they are often taken for fossils or artificially fashioned objects. They may be as small as the head of a pin, or several feet in diameter, with all intermediate sizes. Some of the most curious forms are of clay. Flints are found in many limestones, as in the chalks of England. Sometimes they form layers interbedded with the limestone. They are due to the solution of siliceous shells and sponge skeletons and the aggregation of the dissolved matter. So also carbonate of lime may form concretions, as, for example, the grains of oölitic limestones, which have been found in process of growth in modern seas. Similar oölitic concretions make up the iron ores of the Clinton epoch.

FIG. 100.—Clay-ironstone concretion, Portage group, shore of Lake Erie. Photograph by N. Y. State Museum.

The nodules are often formed by the deposit of matter in concentric layers about some object, commonly a fossil. Elongated concretions containing perfectly preserved ferns are found at Mazon Creek, Ill. Sometimes concretions in drying develop a network of cracks within. These cracks may fill with other material, giving the mass the appearance of a turtle; hence the common name turtle-stones. The geologist calls them septaria. Sometimes they are 3 or 4 feet in diameter, and sections of them polished are used for ornamental work. Decomposing organic matter, or waters

FIG. 101.—Hand specimen of crumpled gneiss. Photograph by G. H. WILLIAMS.

bearing a cementing substance, may by infiltration from a center bind surrounding particles together, as the grains of a sandstone, making a kind of concretion which in some cases is crossed by the original planes of deposit.

If a cavity formed in any manner becomes lined with crystals, the structure is called a geode. It agrees with concretions in being concentric.

212. **Folds.***—These are chiefly important in sedimentary rocks. Unstratified masses might be folded, but they are commonly so broken and disturbed as to obscure the folds

* The student may profitably consult also the text and the illustrations in the section on mountains, pp. 254–262.

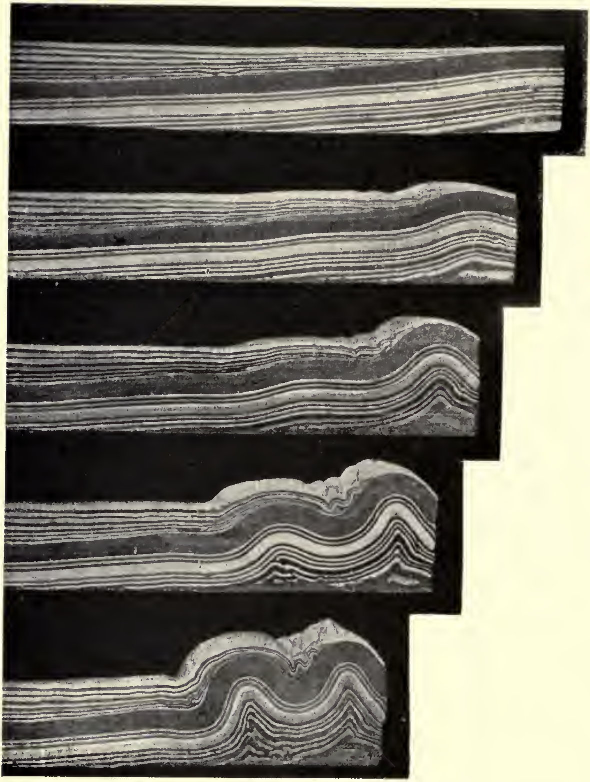


Fig. 102.—Folds made in laboratory, Willis. The block thickens and the crumpling increases with added pressure.

that may have been formed. Rocks are folded by pressure following the direction of the bedding planes. The distortions vary from small wrinkles seen in a hand specimen to folds several miles in height. In the latter case a territory some scores of miles wide and many hundred miles long may be affected. Folds identical in appearance have been made in the laboratory by Willis and by Cadell (Scotland). A pile of thin sheets of rocky matter was artificially made, put under a heavy load, and subjected to powerful side thrust. These experiments are important because they help us to understand the making of the greatest mountains. The student may imitate the process by taking a stack of sheets of paper in both hands, and crumpling them into a series of up-and-down folds.

A fold whose bend is upward is called *anticlinal*, or an anticline (meaning, inclining in opposite directions). A line running with the crest is the axis, and the rocks on either side make the limbs of the fold. Folds are close or open, according to the amount of force used in their making. The Alps illustrate the former case, the Jura and the northern Appalachians the latter. Close folds rarely stand upright, but tip or are completely overthrown. Thus the top of the Jungfrau, one of the high Alpine summits, is composed of most ancient crystalline rocks, surmounting, by overturn, sediments of vastly younger age.

The down-fold, which is found in alternation with the up-fold, is *synclinal* or a syncline. A line running with the trough is the axis, and the rocks rising on either side are the limbs of the syncline. One of these inclines forms at once the limb of the syncline and of its adjoining anticline.

It must not be thought that the ridges and troughs of such folds commonly appear as surface features. They are nearly always destroyed by erosion, and their existence must be learned in other ways. Often a valley follows the anticline, and a ridge or mountain the syncline. Or the upturned edge of the hardest stratum in the folded series

Fig. 103.—Anticlinal fold in sandstone, near Hancock, Md. U. S. Geological Survey.

stands out, as the Medina sandstone, for example, forms the mountain ridges of eastern Pennsylvania.

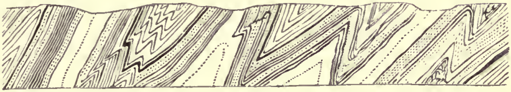


FIG. 104.—Sharply contorted and greatly denuded strata.—From LOGAN.

As some folds are close and others are open, others still are so open that they become scarcely more than gentle undulations of strata. Such faint foldings may appear on either side of a powerfully disturbed region, representing the fading out of the compressive force.

*Monoclinal folds.*—If a bed or stratum passes from one horizontal plane to another by means of a bend or double curve, the fold is called monoclinal, or a monocline.

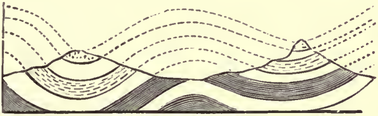


FIG. 105.—Open folds; valley along the up-fold; ridges along the down-folds.

213. **Dip.**—Rocks disturbed as above described are made to incline more or less with a horizontal plane. The angle of inclination is the dip. The term is usually reserved for beds which slope by reason of deformation, while we speak of the *inclination* of beds which have this attitude by original deposit. The dip varies from zero to 90°, when the beds become vertical. The geologist records the amount of dip and its direction, as N. 20° W. or E. 40° S. By knowing the dips at many points and plotting them on a map, the existence and extent of great folds can be determined, or the depth of certain strata at a given point be made out. Thus a geologist may be able to find the depth of an oil- or

water-bearing bed or of a coal seam. The dip is determined by an instrument called the clinometer.

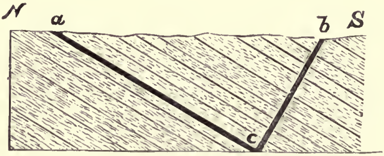



FIG. 106.—Section of inclined strata. To find the thickness *b*, *c*, we solve the right-angled triangle *a*, *b*, *c*, of which we have the angle *a* (the dip), and the hypotenuse *a*, *b*.

214. **Strike.**—This is a horizontal line, perpendicular to the dip, and may be straight or curved. The more rapidly the direction of the dip changes from point to point of a given bed, the more curved or broken is the line of the strike. "If a piece of slate be held in an inclined position and lowered into a vessel of water, the wet line will represent the strike" (Scott). If the vessel be a pan with flaring sides, the intersection of the water plane with the sides will illustrate a curved strike.

215. **Outcrop.**—This term is often used of any natural exposure of rock. It may also stand for the belt along which a given stratum would be exposed if there were no soil cover.

216. **Unconformity.**—If a rock mass is subject to erosion, and the newly sculptured surface is submerged and other

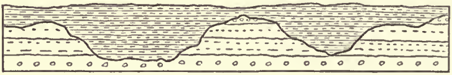


FIG. 107.—Unconformity. Here the history recorded is: deposit; uplift without tilting; denudation; submergence; deposit.

strata are laid down, the discordance between the strata is called unconformity. It has great importance, because it shows difference, and often vast difference, in age. The beds below the unconformity are elevated above the water level, and commonly tilted as well as denuded, before the upper beds are deposited. Fig. 107 shows elevation, erosion, and subsequent deposit, without tilting. Of course resubmergence must follow erosion, to admit of new deposits.

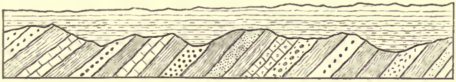


FIG. 108.—Unconformity. Here the history is: deposit; uplift with tilting; denudation; submergence; deposit.

In Fig. 108 tilting is added to the series of changes, and we can see how much of history is revealed by a single section. Thus a series of beds was first laid down. Later, the beds were tilted to a high angle, and then planed down.

FIG. 109.—Unconformity. Conglomerate on quartzite, Ouray and Silverton Toll Road, Col. Dark spot due to shadow of overhanging conglomerate. Photograph by the author.

Subsidence followed with deposit of the overlying strata. The student must not expect to find an unconformity

16

exposed for more than a short distance in a region covered with soil and vegetation.

The break in continuity of deposition may be short, or it may comprehend geological eras. Thus if beds of lake mud rest on Algonkian limestone, the break comprehends all of Paleozoic, Mesozoic, and Tertiary time. The red sandstones of the Connecticut Valley lie unconformably against the crystalline rocks of the uplands. Here the gap is vastly shorter.

### Structures common to All Rocks

These fall under four heads. Joints and veins are equally important in the several kinds of rocks. Faults may occur in all, but are more conspicuous and more readily detected and measured in the bedded rocks. Cleavage may affect all rocks, but in the case of sediments, often nearly or quite destroys the planes of bedding.

217. **Joints.**—In sedimentary rocks there are commonly two sets of dividing planes, nearly perpendicular to the planes of bedding and to each other. They thus roughly cut the mass into rectangular blocks. Almost any cliff shows this, and the work of quarrying is thus greatly aided. Often one system of joints is more perfect than the other, and may show on exposure a very perfect and smooth wall face. The effect of joints on erosion has been noticed in Part I. The frequency of joints in bedded rocks is variable. Sometimes they crowd one another at intervals of an inch or less. At other times they are one, two, or more feet apart, up to ten or twenty, as seen in some very large flagstones. Joints are common in igneous rocks, as granite and basalt. The peculiar columnar jointing of lavas will be described under the structures peculiar to igneous rocks.

In regions of much disturbance the joints may be very perfect, and be found cutting one another at various angles and in several systems, even as many as six or seven. The slates of Somerville, Mass., show this well. Joints are not confined to the more ancient, or even the fully consolidated rocks. They are sometimes well developed in clays which have been subject to drying and to little pressure.

218. **Origin of joints.**—Some joints may be due to shrinkage in drying. This and the presence of elaborate jointing in some slates point to dynamic pressure as the important cause. All parts of the earth's crust must be subject to

Fig. 110.—Stream bed, Ausable River, showing two systems of vertical joints.

strong pressure, even where there is no metamorphism. Similar results have been produced by experiments with blocks of ice. An account of this may be found in Dana's Manual of Geology, p. 372. It is probable also that shocks of earthquakes are effective in making joint structure.

219. **Faults.**—These are dislocations in which a mass of rock moves on the adjacent mass along a plane of division, commonly a fracture. More often the movement is vertical, or at a moderate angle from the vertical, and car-

Fig. 111.—Normal faults; escarpments not removed by denudation.

ries sedimentary strata out of correspondence with each other. Faulting usually goes with powerful folding, producing most complicated arrangements of the rocks concerned, especially when obscured by erosion and surface deposits. The amount of dislocation is called the throw, and varies from a fraction of an inch to many thousand feet. The limit is the depth at which all rocks become plastic with pressure and heat. Faults may extend for scores or hundreds of miles. Toward the end the throw diminishes and the dislocation runs out. A region may be broken into stupendous crust blocks by crossing systems of faults. Mountain ridges and intervening lake basins may be due to faults, as in the Great Basin.

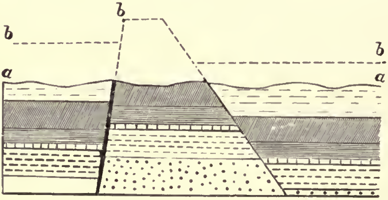



Fig. 112.—Normal faults; escarpments worn away. Broken lines show outline of country if there had been no denudation.

It must not be supposed that the rising wall of a fault generally forms a cliff. Often no sign of such dislocation appears in the topography. Either the faulting goes on so slowly that the cliff can not develop, or is of such ancient date that it has been destroyed by erosion. In the case of recent faults the escarpment sometimes appears.

220. **Examples of faults.**—As already cited, the mountains of the Great Basin region are vast tilted fault blocks.

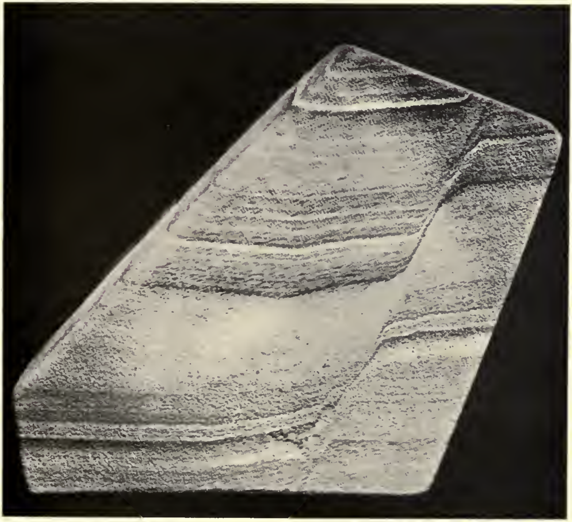


FIG. 113.—Banded sandstone, Dakota, showing faulting.

Lesley describes a fault of 8,000 feet throw in southern Pennsylvania so cleanly formed that one might plant his feet on both sides of the plane of movement. Dislocations of 2,000 feet are described as occurring along the Appalachians. A series of north and south faults have brought up across the Mohawk Valley ancient gneisses, which would otherwise be buried several hundred feet below the river.

Along the Pennine Chain in Yorkshire, England, is a fault fifty miles long with a throw of 4,000 feet.

FIG. 114.—Fault in Gering sands, south of Crawford, Neb. Photograph, 1897, by N. H. DARTON.

221. The hade of a fault is the angle which its plane makes with a vertical. The overhanging face is called the hanging wall, while the other face is called the foot wall. If the hanging wall goes down relatively to the foot wall, we have a normal fault. It is such as would be produced by tension, causing a spreading of the masses concerned, or it might be due to gravity alone, if support were weakened below. If, however, the hanging wall goes up relatively to the foot wall, we have a reversed fault. It is such a movement as would be caused by thrusting together masses on

two sides of an inclined plane of division. Both thrusts and pulls may well be incidental to the general shrinkage of the earth's crust.

A fold may by extreme pressure pass into a fault. The thrust may then be so great as to carry one mass of strata several miles over upon another. This is called an overthrust fault. An overthrust of 11 miles occurs in the beds of eastern Tennessee. Similar gigantic thrusts have occurred among the rocks of the Scottish Highlands. A monoclinal fold may pass into a fault, as seen in Fig. 115. A dislocation of this sort may take place along several planes by a series of faults of small throw. Thus

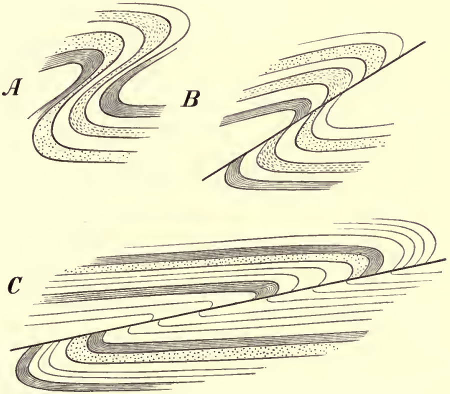



**Fig. 115.—Diagrams showing successive stages (A, B, C) in the making of a reversed or thrust fault.**

we have a step fault. Along the plane of faulting, instead of clean faces there may be a zone of crushing several or many feet thick. Rock surfaces powerfully moving on each other form highly glazed surfaces, known as slickensides.

The same bed may, through faulting, appear repeatedly at the surface, as in Fig. 116. This principle is of great importance in mining. Suppose *c*, *c*, *c* in Fig. 116 to be beds

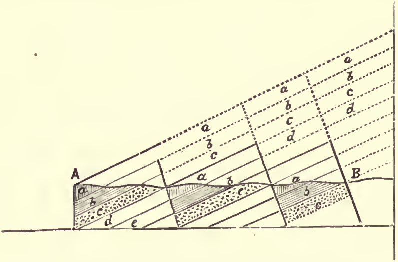



Fig. 116.—Repetition of strata by faulting.

of coal. False expectations would be raised if two of these were not ascertained to be but small sections of the one original seam.

### Veins

222. **Definition.**—A vein is a sheet or mass of one or more minerals formed by the slow filling of a fissure or cavity, or by replacement of more or less of the original substance of the rock. The term is often popularly used where seam or bed should be employed, as of deposits of coal, salt, or iron ore. Veins naturally occur most frequently in regions of disturbance, where the subterranean geological processes are active. They are the most prolific source of the more valuable metals, of rare minerals, and of gems.

223. **Origin of cavities.**—This may be due to shrinkage, as in drying or cooling. Often a thin vein deposit is made along joint planes, where no special dynamic activity has occurred. Other cavities or pockets are formed by solution, and may be filled with vein material if small, or may enlarge into caverns. Certain ores of lead, as at Galena, Ill.,

lie in solution pockets in limestone. By far the greater number of veins are formed in fissures, due either to faulting, folding, or earthquake shocks. Fissure veins vary in thickness from a fraction of an inch to several or many feet.

224. **Modes of filling.**—This process is believed to be accomplished in several ways. (*a*) *By lateral secretion.* Particles of mineral are dissolved and carried out from the rocks and deposited in adjoining crevices. The character of the vein would depend upon the composition of the local rock. (*b*) *By descension.* Waters flowing down from above may deposit dissolved matters. Thus stalactite formations are closely related to such veins, and might be traced up into veins of this nature. (*c*) *By ascension.* Heated waters come from below, depositing on their way

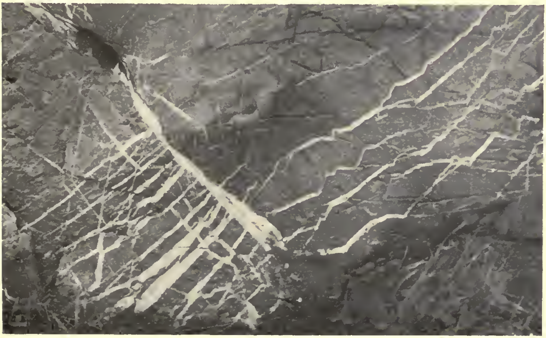


Fig. 117.—Veins of calcite, Highgate Springs, Vt. U. S. Geological Survey.

the vein materials. The incrusting of pump and boiler pipes is an illustration of such effects. Similarly a fissure may be filled through the medium of ascending vapors, whose mineral matters are sublimated as they rise, through loss of the heat by which they were brought to a gaseous condition.

225. **Veins without fissures.**—Replacement of some minerals by others may go on by means of percolating waters. We may have a rearrangement of minerals already present, or an importation of others from a distance. Such mineral masses are not typical veins, as their boundaries are obscure and their forms quite indefinite.

226. **Further facts about veins.**—Some veins show a banded structure. A mineral may be deposited in thin sheets on either side of a fissure. These sheets may then be overspread by others due to waters or gases carrying a different substance. The banding may be due to a filling

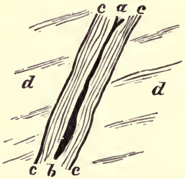



Fig. 118.—Vein structure, showing banding.

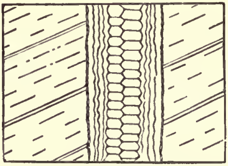


Fig. 119.—Vein structure. Banding and combs of interlocking crystals.

of the fissure and reopening, giving opportunity for another sheet of mineral to form alongside the first. Sometimes the vein carries off a mass of the rock wall, which is then closed in on the rent face by vein matter. Such an isolated mass is called a "horse." Some veins show comblike structure, due to the formation of interlocking layers of crystals on both sides of the fissure. Miners often find a clayey selvage between a vein and the country rock, due to grinding or to decomposition.

227. **Veins and metallic deposits.**—If a metal is not in composition or chemical union with some other substance, it is called "native," or "free." Gold almost always occurs

in this way, and silver not infrequently. Thus also the copper of the great mines of northern Michigan is free. An ore is strictly a metal united with a non-metallic substance. The term is loosely employed, however, and is, for example, used for quartz which contains gold. The gold is free, though generally so finely disseminated as to be invisible. Many ores contain several metals. Much of the silver ore of the West yields a large quantity of lead with small amounts of gold and copper. Ore is an economic term, not being used unless a metal is present in workable quantity.

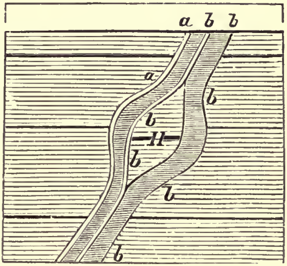


Fig. 120.—Vein structure, showing horse, *H*.

The most important ores of precious metals are found in great fissure veins. These are apt to be parallel in a given region, and go far down, as in the famous Comstock mine in Nevada, which is closed to development below a certain level by the abundance of heated waters. We should expect great fissures to furnish metalliferous veins because they go deep, furnish a highway for subterranean waters, and are themselves attendants of disturbance and consequent metamorphic action. Parts of such veins may be rich and others of no value. A columnar body of ore in a vein is a "chimney" or "chute." A great pocket of precious ore is a "bonanza." The vein stone or matrix is the "gangue," and fragments of a vein broken off at the surface are called by the prospector "float" or "blossom."

228. **Bedded ore deposits.**—Such are most ores of iron, the lead already mentioned, and some silver ores, as at Leadville and Aspen, Col. By old mining law, a mining claim follows the vein, even though its angle with the hori-

zon carries it below an adjacent area. The evident injustice of this in wide-sweeping bedded deposits led to an interesting change in the law, limiting the horizontal extension of claims.

229. **High- and low-grade ores.**—These are relative terms, and the usefulness of a low-grade ore depends upon the perfection of the processes of reduction. With the progress of invention, ores are now worked which were formerly cast upon the dump heap. The more valuable metals, such as gold and silver, are reckoned in ounces per ton; the less valuable, as lead, in percentages of the whole. Reduction employs various processes of crushing, concentration, roasting, and smelting, which can not be explained here.

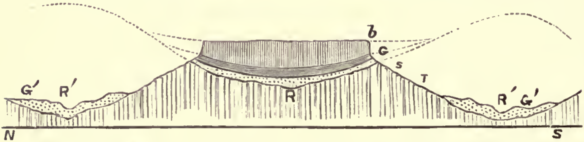



FIG. 121.—Table Mountain, California. Broken line shows profile of ancient mountains. *b*, lava filling of old valley; *R*, gravels of this ancient river bed; *R′*, *R′*, present river beds.

230. **Placers.**—A placer is a deposit of gravel containing particles of free gold, or of tin, platinum, or other ores. The gravels may be of alluvial or glacial origin, and they are derived from the wear of rocks with metalliferous veins. The gravels may belong to an ancient stream, as at Table Mountain, California, where a valley was filled with a lava stream, and the gravels since made accessible by denudation are found to yield gold (Fig. 121). The gold dust and nuggets, being heavy, are found more abundantly at the bottom of the gravels. Placer beds may be found under the borders of the sea, as at Cape Nome, Alaska. "Stream tin" occurs abundantly in Australia, and to a lesser extent in California and other parts of the West. We have here a natural process of crushing and partial concentra-

tion. Various methods are used to finish the work of concentration. Among these are the primitive pan, with which the miner agitates the gravel in water, and the "cradle," a small sluice with "riffles" (crossbars) which catch the heavy gold as a gravel-bearing current of water is sent over them. Hydraulic mining proceeds on the same principle, but on a large scale. A powerful current of water is sent against the gravel bank, whose materials are carried through a large sluice with riffles. The flooding of good fields by these gravel-bearing streams became so disastrous in California as to require regulation by law.

231. **Cleavage.**—We have already studied several sorts of divisional planes, such as those of bedding, joints, and fracture with or without faulting. Cleavage is found especially among metamorphic rocks, and by virtue of it the mass may split into thin leaves. The structure is typically developed in slates, and hence is sometimes called slaty cleavage. It differs from foliated structure in the perfection with which rocks affected by it split into broad thin sheets, and also in the evident appearance in foliated rocks of the flakes or scales of the minerals. Cleavage passes across the planes of bedding, and nearly or quite obliterates them.

Pressure is believed to be the cause. The cleavage planes are found to be at right angles to the direction of the force, as may be clearly seen in mountain masses. Constituent grains in the rock may be found flattened and elongated, and fossils that survive are apt to be distorted from their proper forms. Cleavage has been artificially induced, as in pipe clay mixed with scales of iron oxide, or in beeswax.

## General Structure or Mode of Occurrence of Igneous Rocks

Melted rocks have solidified on the surface at moderate depths, and in deeply buried parts of the earth's crust. In

Fig. 122.—Palisades trap sheet breaking across beds of Triassic shale, Weehawken, N. J.

the last case we are able to observe them only because they have been brought to light by extensive denudation. Igneous rocks formed at the surface are lavas, and having cooled quickly, as compared with those which are deep-seated, are less crystalline and often vesicular.

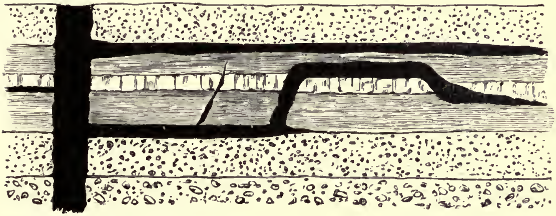


FIG. 123.—Diagram showing dike and intrusive sheets, one of which breaks across the strata.

232. **Volcanic cones and necks.**—Cones have already been described in our account of the workings of volcanoes. If we could remove the cone of an extinct vent and strip away its foundations, we should doubtless find a column or plug of igneous rock extending downward to the deep

FIG. 124.—Laccolith (after GILBERT). This ideal section is drawn as if no denudation had taken place.

sources of the lava. Nature has done this in some cases and left the eroded stump projecting above the surface, owing to its greater hardness. Such a stump is called a volcanic neck. Many are found in New Mexico and other parts of the West.

233. **Sheets.**—In a number of regions in later geological times large areas have been covered with outpourings of molten rock without the formation of cones and without evidence of a single or central vent. The discovery of great dikes, or lava fillings of ancient fissures, goes far to prove that these sheets are due to eruptions through cracks in the earth's crust. Such accumulations occur in Colorado, Utah, Idaho, Oregon, Washington, and other Western States; also on the west coast of Scotland, in Abyssinia and India.

Fig. 125.—Granite dike cutting crystalline limestone, 192d street, New York City. Photograph by N. Y. State Museum.

Other sheets have been intruded between beds of sediment, and their surfaces or edges since exposed by erosion. Sometimes, as in the lava sheets of the Connecticut Valley, and those that form the Palisades of the Hudson, the igneous rocks have suffered tilting or other deformation along with the sediments which inclose them. If a lava flows between two layers of sediment, the latter will be baked by the heat both above and below. If a sheet of lava has in some ancient time overflowed the surface, and

Fig. 126.—Dike, Avalanche Lake, New York. The dike is worn away more than the adjacent rock, and a waste slope is built into the lake.

(Copyright, 1888, by S. R. Stoddard, Glens Falls, N. Y.)

after cooling has been covered with a deposit of sedimentary rock, the under surface of the latter will not show change. Sometimes the lava has left the plane on which it was flowing and torn its way across other beds, to resume there a direction parallel to the first (Figs. 122 and 123). The hanging hills near Meriden, Mount Holyoke, and Mount Tom, the Palisades of the Hudson, the Watchung Mountains near Orange, N. J., and the Salisbury Crags in Edinburgh, furnish well-known examples of sheets. In all these cases the beds have been tilted and subjected to vast erosion. All gradations may occur between wide sheets of nearly uniform thickness and the structures next to be described.

234. **Laccoliths or laccolites.**—It has been found that some masses of lava, issuing from the seats of volcanic energy, did not reach the surface of the earth, but, having broken through part of the overlying rock, heaved the still unbroken layers up into great domes (Fig. 124.) If surface erosion had not taken place on these domes, it would be nearly or quite impossible to show their origin. But they have been so deeply dissected that the underlying lavas are brought to light, still bearing sloping remnants of the uplifted sedimentary beds. This kind of volcanic structure was first adequately studied by Mr. G. K. Gilbert, of the United States Geological Survey. He found that the Henry Mountains of Utah are of this sort, and applied the term laccolite (stone cistern) to such masses of lava. Some mountains of western Colorado belong to the same class.

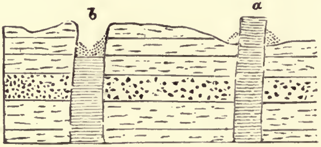



FIG. 127.—Topographic effects of hard and soft dikes intersecting sedimentary beds.

235. **Dikes.**—A dike is like most veins in form, and, like a vein, is found along fractures or other planes of division. The fissure is, however, filled rapidly by a flow of molten

rock, rather than slowly by rock matter from solution. The dike is a casting run into a mold. Dikes are most variable in thickness, ranging from less than an inch to many feet. Fifty dikes from 1 to 75 feet wide and 13 miles

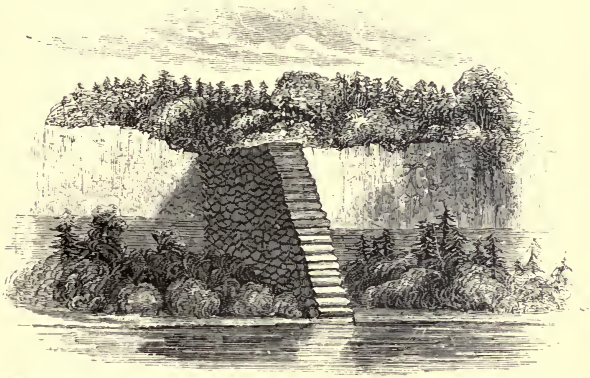


FIG. 128.—Dike, Lake Superior (after OWEN); adjacent rocks weathered away. Note the horizontal columns and compare with Fingal's Cave, Fig. 129.

long are said to occur in the Triassic sandstones of North Carolina. The rock in a dike of any width, is usually more coarsely crystalline in the central portions, where cooling is slow, but finely crystalline or glassy near the walls, where cooling is rapid. Lines of flowage are often found, and these, with the varying crystalline characters of the different parts, are among the tests by which a dike may be distinguished from a vein. Local metamorphism may be found in the bounding rocks also. If the rock be hard or soft, we may have a trench or a wall where the dike comes to the surface (Fig. 127). Dikes may thus form naturally fenced fields, as cited for one place in Scotland; or we may find a line of bowlders, or vegetation or fresher green over the dike, to mark its presence. Dikes are

Fig. 129.—Columnar basalt, Fingal's Cave.

among the most common structures, which students in some regions will see in their field excursions. Professor Shaler estimates 5 to 10 per cent of the surface of Cape Ann as occupied by them. Dikes of different ages often intersect each other, the later ones breaking continuously across the earlier. They are often offshoots of volcanic necks, bosses, or sheets, and cones are often ribbed with them.

236. **Columnar structure of lavas.**—This occurs in marked perfection and is a form of jointing. The columns are polygons in form, from a few inches to several feet in diameter, and are seen in especial perfection in many sheets of basalt, as at Fingal's Cave and the Giant's Causeway. The entire island of Staffa, several adjacent small islands, and the shores of Mull illustrate this structure on a large scale, as also the Palisades of the Hudson, and Obsidian Cliff in Yellowstone National Park. The axis of the columns is always perpendicular to the plane of the sheet or dike. Sometimes each column is divided into sections by a kind of ball-and-socket joint whose origin is obscure. Nor is the columnar jointing well understood, but is believed to be due to contraction in cooling.

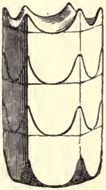


FIG. 130.—Basaltic column, showing ball-and-socket joints.

## CHAPTER XIV

### PHYSIOGRAPHIC STRUCTURES

Having studied the minute and gross structures of rocks, we must now see how these, taken together and acted on by geological forces, make up the larger elements of the earth's crust. We shall notice two or three great principles, review the chief kinds of physiographic form, such as plains, mountains, valleys, and shore lines, seeing finally how these develop together and lend form to continent and ocean basin, and thus give to the globe its surface expression.

237. **Definition.**—Physiography means, according to its derivation, a description of Nature. It is so used by some English authors. In America it is sometimes applied to physical geography as a whole, but more commonly to the science of land forms. We here use the word in the latter sense. It is the study of land forms, including the topography of ocean basins, in the light of their origin, or from the point of view of geology.

238. **Land mass and land sculpture.**—We may profitably think of the exposed parts of the earth's crust as a block upon which erosive forces work, much as the artist uses his tools upon a piece of marble or granite. We have seen that the tools for earth sculpture are various, and work in many ways. Consider a given mass of land. The atmosphere covers it; its oxygen enters into combination everywhere, and the winds tear its surface, modify its rainfall, and send waves upon its shores. Streams form and

run over it, and glaciers destroy or build upon its surface. It rises and sinks relatively to sea level, it is shaken by earthquakes, folded and broken by compressive forces, dotted with volcanic cones, or flooded with broad streams of molten rock. Meantime life flourishes, and the changing panorama of form and color moves before the eye, or is revealed to the diligent student of the earth's history.

239. **Land sculpture and rock structures.**—Land form depends not more on geological forces than it does upon the rock structures studied in Chapters XII and XIII. Whether the rock is hard or soft, soluble or insoluble, crumbles easily or holds together firmly—all these conditions influence largely the effectiveness of erosion. So, too, the large structures are no less important. Let us take, for example, the topographic effects of stratification. Hard and soft beds often alternate with each other. If they lie horizontally, a hard bed which can not easily be destroyed will at length form the top of a plateau or tabular hill. Or it determines the existence of a waterfall, or makes a retreating wall of rock precipitous instead of sloping.

Folds give character to all the great mountains of the earth. In every variety of strength, size, and combination, folds carved by geological implements give us the scenery of the Appalachians, the Cordilleras, and the Alps. Powerful folding is combined with faulting, and in some cases faulting is the main feature, and along with these structures go those of the igneous rocks, the dike, sheet, laccolith, and volcanic neck, in every degree and kind of association.

240. **Land modeling.**—Here we may include topographic changes and forms which might appear under the head of land sculpture. But as they are made by deposit rather than erosion, the term modeling is more suitable. Many forms of land waste, made by rivers, glaciers, winds, or waves, belong here. Taken all in all, therefore, the forms of the lands are very complex in their origin. A hill,

mountain, or lake basin, has its form determined by a network of geological forces and structures in endless combination.

## A. Elements of Land Form

### *Plains*

241. **Marine plains.**—The term plain is applied to a comparatively even surface which lies near the level of the sea. Such areas originate in several ways, but marine plains are the most important type because they are found more or less on the borders of all continents and may be quite large. Such a plain is a marginal sea bottom, slightly elevated above the water level. One of the best illustrations is the Atlantic coastal plain of the United States, extending from New Jersey to Florida. It consists of nearly horizontal, often unconsolidated, beds of gravel, sand, and clay. Two agencies are especially concerned in its formation : first, deposition of land waste and subsequent upward oscillation. It has been channeled by streams in a moderate way since its uplift.

242. **River and lake plains.**—A river, by its windings, may at length cut away the hills and form a plain of considerable width, which it also strews with land waste. Such plains often form inward extensions of coastal lowlands, as in the case of the Mississippi. Both are covered with land waste, but only the coastal plain has been submerged. Lake plains, like those of marine origin, are formed by sediments in standing water. We find a multitude of small lake plains or lake floors, where the waters have dried away or been drained by the lowering of the outlet passage. In case of partial drainage, a lake plain borders the remnant bodies of water, as about Lake Erie or Lake Ontario.

### *Plateaus*

243. **Definition.**—A plateau is an elevated plain of some extent. As the term is used, there is less uniformity of

topography than in the case of the plain. Considerable hills or mountains may break the surface, which can only be called a plain when great areas are considered. There is no limit of altitude fixed by Nature, but 1,000 feet is usually considered as a dividing limit. By this standard the so-called Great Plains of Nebraska, Kansas, and Colorado form a plateau. The plains of the Mississippi merge into it.

244. **Structure of the rocks forming a plateau.**—This depends upon the structure of the plain by whose uplift a plateau is commonly made. The rocks would therefore sometimes be nearly horizontal, in the altitude of original deposition. This is the case with the Catskill or Alleghany and Cumberland plateaus, stretching from New York to Alabama; with the great plateau east of the Rocky Mountains and with the plateaus of the Colorado River. But sometimes the rock beds stand at high angles with the plateau surface, as in western Massachusetts and Connecticut, in the Highlands of Scotland and the Rhine. In these cases high mountains have been worn away, leaving a peneplain, by whose uplift the plateau is formed.

245. **Relation of plateaus to plains and mountains.**—The plateau may grade down into the plain, as west of the Mississippi River, or it may descend by an escarpment. The term escarpment is loosely used, and may refer to such precipitous fronts as bound the Catskill plateau on the east, or the steep hill slopes by which the same plateau descends to the plains of central New York. Plateaus may be buttressed against high mountains on one side, as the Bavarian plateau and the Alps, the Spanish plateau and the Pyrenees, and the trans-Mississippi plateau and the Rocky Mountains. Some plateaus are high basins between still loftier mountains. Such are the Great Basin and the Colorado plateau of the West, the plateau of Bolivia, and, most stupendous of all, Thibet, the plateau of central Asia, whose altitude is as great as that of many Rocky Mountain sum-

mits. On the other hand, the Cumberland plateau is as high as the adjacent Appalachian Mountain ridges, while the Scottish Highlands are not associated with any higher elevations.

FIG. 131.—Plateau with horizontal strata, considerably trenched by valleys.

246. **Dissection of plateaus.**—In consequence of high altitude, stream work and general valley-making are effective in plateau masses. The exception to this is found when a plateau is hemmed in by mountain barriers. For this reason the Great Basin plateau can not be channeled by streams except along the slopes about its margin. The Colorado plateau, on the other hand, has been profoundly dissected by the great river and its branches. All stages of dissection are found. The elevations of a maturely dissected plateau are often called mountains. Thus the Catskill portion of the great eastern plateau of the United States is called the Catskill Mountains. It is mountainous in height but not in structure. In Scotland, however, we have mountain height and mountain structure as well.

*Mountains*

247. **General considerations.**—The highest interest gathers about mountains. Their structure and origin have long fascinated students of the earth; their beauty and majesty have filled the thoughts of poets and of all lovers of Nature, and they profoundly influence climate, the distribution of organic forms and the history of man. More than other features of Nature, the mountains and the sea leave their impress upon character and habits. Compare the Swiss and the Dutch, while the Greek, the Scandinavian, and the Scot has often lived in the presence both of the mountain and the sea. The study of mountains in these relations belongs to Physical Geography and History. We must here

examine the origin and form of mountains as determined by geological forces.

248. **Definition.**—Mountain is an indefinite and popular rather than strictly scientific term, and loosely covers all eminences which rise to a considerable height above their surroundings. An elevation of a few hundred feet rising from a plain might be called a mountain, while in other positions it would be named a hill. The best distinction is that which confines the term to heights due to deformation of the earth's crust, accompanied by erosion. Bearing in mind this distinction, we may then follow the popular use of the term as applied to volcanic cones, or high masses carved out of undisturbed fragmental beds, like the Catskill Mountains, or some of the "table" mountains of the West. In this discussion we keep to the more strict use of the word.

249. **Analysis of mountain aggregates.**—A mountain range consists of several parallel ridges, of considerable length, which have been formed in one epoch of disturbance, or by one prolonged crushing movement. The ridges may be the original arches of upheaval, or anticlinal folds, but more often they are outcropping ridges of resistant rock, remaining after long erosion. The ridges are often of different length, as might be illustrated by the parallel folds of a garment. The Appalachian folds, extending from Catskill, N. Y., to Alabama, form a range; likewise the Sierras or the Coast Range of California. A ridge is more or less divided into peaks, depending upon the extent of erosion and dissection which has taken place.

A mountain system consists of several ranges in the same region, more or less parallel to each other, but made in different periods of geological time. Thus the eastern United States has several times been the theater of mountain-building, and its whole assemblage of ranges is called the Appalachian system. The student should notice the wider use of the term Appalachian in this connection. It is unfortunate that the same word should be used for a system and for one of the ranges which compose it, but the usage is general. The Green Mountains, the Adirondacks, and the Blue Ridge Mountains are other ranges of this great system. Some authors use the word chain for an aggregate of ranges and employ the word system in another sense.

250. **Origin of mountain ranges.**—It is not possible in the present state of knowledge to make a complete statement, much less in an elementary text-book. But students have no doubt of the general truth of the origin of mountains through the shrinking of the earth's crust and the wrinkling of certain parts of it. We must see what sorts of rocks compose mountains, what forms these rocks have taken, and how mountains lie with reference to sea and land. It is found that thick masses of water-laid rocks enter into most mountain chains. The thickness is estimated at 40,000 feet for the Appalachians and 50,000 for the Alps. Many of these beds are sandstones and conglomerates, and all are rocks formed alongshore or at moderate depths in ancient seas. Many great mountain chains, like the Andes, are close to the sea border, and others, like the Appalachians, were close to a sea border at the time when they were made. Often a core of crystalline rocks, such as granite, is laid bare by erosion along the crest of a mountain ridge, as if squeezed up in the time of folding. The Rocky Mountains furnish an example. The sedimentary rocks of mountains are often crystalline through metamorphism, but in other cases they are unchanged. This points to a slow rate of elevation and compression. Indeed, if mountains were growing in a region it might not be evident, save by slips producing earthquakes, or by refined observations reaching over a period of years.

Following Le Conte, the origin of a mountain range may be explained as follows: It is found, as above stated, that very thick blankets of stratified rocks compose the bulk of many mountains. These rocks thin out toward the plains. Thus, as we pass from the Appalachians to the Mississippi River the pile of sediment is but one tenth of the thickness which it has in the East, and contains no shore formation. These are the conditions that we find in going from a sea border oceanward. A subsiding sea margin is the only place where a thick mass of coarse sediment could be made. Hence we may be well assured that sea borders are the theater of mountain-making. For reasons which are less clear than the fact itself, here seem to be found the weaker and more yielding belts of the earth's crust. Hence here the strata are mashed together, and there is no relief save by up-and-down folding and crushing, with faulting and occasional overthrust.

251. **Age of mountain ranges.**—This subject will be better understood as we come to the growth of particular ranges in the course of the earth's history. It is enough here to notice the general means of fixing the period of formation. It is plain that if beds of rock are folded and broken, they were deposited before the mountain-making took place. These broken and upturned beds may be covered at the base of the mountain by beds which have suffered no disturbance. The mountain, then, is certainly older than these. In other words, the existence of an unconformity helps us to know within narrower or wider limits when a mountain range grew. The coal-bearing rocks of eastern Pennsylvania are folded in, and hence the mountains are later than the time of coal formation. But the Mesozoic beds are not affected, hence the Appalachian folds are put between Paleozoic and Mesozoic time, and their making was the event that in America separated these great divisions of geologic time.

252. **Form of mountains.**—A few general principles only need here be stated. Mountain form depends on at least four factors: (1) Erosion forms peculiar to certain kinds of rock. Here we may cite the dome form of many gra-

FIG. 132.—In the Eastern Alps; pinnacles developed by erosion and extensive slopes of waste.

nitic mountains, and the rugged and often needle-shaped crags of the dolomite mountains of the Tyrol. (2) Relative resistance of rock masses. We may compare the Medina sandstone ridges of Pennsylvania with the lower slopes and valley bottoms of the shale and limestone, or the crystalline ridges of the Berkshires with the inclosed limestone valley of the Housatonic. (3) Attitude assumed in deformation. Referring again to the Appalachians, we compare the series of folds with resulting ridges and inclosed valleys with the single broad arch of the Uintah Mountains in Utah and Wyoming, or we may note the unequal slopes of two sides of many mountain ridges. One side is the escarpment formed by the broken edges of the strata, and the other is the dip-slope of the rock. (4) Erosion as determined by climate and lapse of time. Compare the sharp summits of the youthful Alps with the rounded crests of the ancient Adirondacks. Precipitous young mountains, with vigorous drainage in their valleys, display a rocky, rugged surface. In older mountains the inequalities are more and more worn away; the waste slopes stretch far up toward their summits until at last they become perfectly "graded."

The declivity of mountain slopes is on the average much less than is commonly supposed. Slopes appear to the eye much greater than they are, and the attention is fixed upon the more rugged parts, and withdrawn from the long inclines by which the principal approach to summits is made. The Italian slope of the Alps is but 10 feet in 100, and the French side of the Jura shows but 2.6 feet in 100.

253. **Typical examples of mountain ranges.**—These will illustrate different kinds of deformation, particularly of folding, and different degrees of destruction by erosion. We take first the basin range of the West, lying chiefly in Oregon, Utah, and Nevada. The dislocation is by faulting, and the range may be taken as the type of fault block

mountains. Their direction is north and south, and the bolder or steeper side of each ridge is the fault cliff, while the more gentle dip-slope of the rocks leads off from the summit ridge on the other side. The form may be roughly illustrated by the tilting of long ice blocks which are crushed against each other, as the entire mass breaks up and moves with the flood.

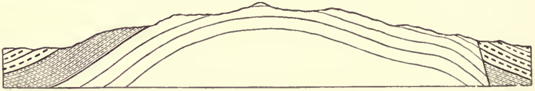


Fig. 133.—Section across Uintah Mountains, showing a single great fold, a fault, and denudation.

When mountains are due to folding, we usually find a number of folds forming a range. The Uintah Mountains, however, offer a striking case of a mountain mass composed of a single mammoth arch. It is cut through from north to south by the cañon of the Green River, which exposes the ancient crystalline rocks that form the foundation of the mountain. But some of the strata of the great blanket of later rocks are carried over the top. The uppermost beds, to a thickness of 3½ miles, according to Powell, have been swept away. On one side the great arch broke, and formed a fault with a throw of 20,000 feet.

A variation from this form is found in the park region of Colorado. The heights and principal breadths of these massive ridges are composed of crystalline rocks. The strata of the plateau on the east and those of the parks lie nearly horizontal, but their edges are everywhere bent up against the foot of the mountains, being ragged through prolonged erosion. In going from Colorado Springs to Manitou, one passes across the edges of these broken beds, seeing them well displayed in the shafts of the Garden of the Gods. Rising from Manitou, we at once begin to traverse the crystalline core of the vast ridge which culminates in Pike's Peak.

In the northern Appalachian type we have a range consisting of many parallel and somewhat open folds. No single fold continues throughout the entire belt of disturbance, though some single anticlines and synclines are upward of 100 miles long. The important feature here is the stupendous erosion which has taken place, for the mountains are old. Some of the anticlinal arches would, it is believed, be from 3 to 5 miles high if destruction had not gone along with the uplift and until the present. The existing mountain ridges, which inclose many long, canoe-shaped valleys, only rise from 2,000 to 3,000 feet above sea level. The deepest valleys are along the axes of the anticlinal folds.

The Jura Mountains afford another illustration of open folds. But they are much younger; erosion and denuda-

FIG. 134.—Section of the Jura Mountains, showing ridges following the anticlines and valleys along the synclines.

tion are in a comparatively early stage, and the ridges are formed by the anticlines and the valleys run along the synclines. Some of these folds are remarkably symmetrical—that is, the rocks dip at equal angles on either side of an axis of folding.

The Alps are a most important illustration of mountain folds, and they have been much studied. Here the folding and crushing were carried to a high degree, close folds, overthrown arches, faulting and stupendous erosion, being the rule. Some of the highest summits, as Mont Blanc and the Jungfrau, are formed of older crystalline rocks overlying younger sedimentary strata. This is due to the complete overthrow of gigantic folds, with the inversion of the beds which form one limb of the fold. Several distinct loups rising above one another in zigzags, can be seen on some of the great cliffs which border the valleys. The intense lateral push has so squeezed together the folds of the central Alps that these folds have fallen over in either direction, producing fan structure (shown in Fig. 135). The Alps are young mountains, the valleys narrow, the slopes steep, and the peaks sharp. Nevertheless, immense

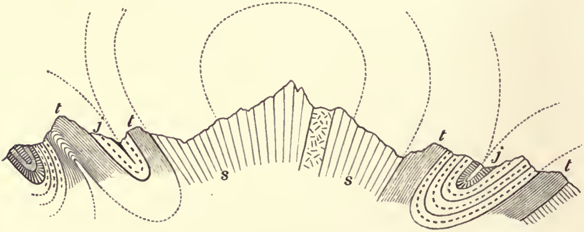



FIG. 135.—Section of a part of the Alps, showing close folding and fan structure. After RENEVIER.

erosion has everywhere been accomplished, and the passes are cut to about half of the altitude of the higher summits. In glacial times all Alpine valleys were occupied and much modified by ice streams.

It remains to refer to some very old mountains which are much worn and low. The Adirondacks are an example. They are indeed higher than the Appalachian folds, although much older. This is due to the harder rocks which form them. The New Jersey Highlands and the Blue Ridge of the Southern States are of the same order, as well as the Highlands of Scotland and Scandinavia.

### *Topography of Volcanic Formations*

253. A number of the more important facts were given in the last chapter, and in the chapter on Volcanoes in Part I. Thus we have cones which are often of mountainous altitude, laccolithic mountains, volcanic necks, and lava sheets. It remains to emphasize the constant modification of these by destructive agencies. In California and in cen-

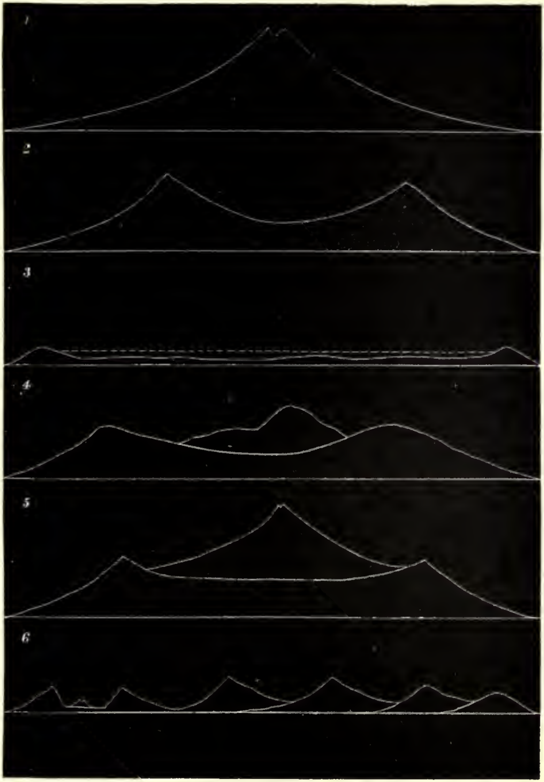



FIG. 136.—Outline of various cones. 1, Fusiyama. 2, Hverfjall (Iceland). 3, Bracciano (crater lake). 4, Rocca-Monfina (Italy). 5, Teneriffe. 6, Vulcano, Lipari Islands, overlapping cones along a fissure.—After JUDD.

tral France cones of some extinct volcanoes are still perfect in form. Others, in eruption in late geological time, even since the Glacial period, show considerable channeling of their slopes. Of these, Mount Shasta, in northern California, is a good example. It is a large cone, having an altitude of 14,350 feet and a diameter at its base of 17 miles. Its slopes have an average inclination of 15°, being greater toward the summit and much less about the base. We may well compare Mauna Loa, with similar height, a diameter of 70 miles, and average slopes of 5°. The breadth of this cone is due to its very liquid lavas. The upper part of Mount Shasta still bears glaciers of considerable size. These and their former extensions have eroded spacious cirques, while below is a belt riven with great cañons, cut by torrents from the glaciers. Farther down, the drainage runs beneath the surface, and a plane zone leads down to the general level.

A much more advanced stage of erosion is described by Dana, as shown by the volcanic island of Tahiti, where profound gorges radiate toward the sea, bounded by precipitous cliffs, at whose crest but a knife edge of the general slope remains.

Following still further the process of destruction, we may cite again Mount Taylor, in New Mexico, and the scores of volcanic plugs in its neighborhood.

Thus we find all stages of topographic development illustrated by extinct volcanic mountains. In a similar way a lava plateau, like any other, is at length dissected, and nearly or quite destroyed, the later stage being shown by the lava caps of table mountains.

### *Hills of Various Origin*

254. Hill is, even less than mountain, a scientific term, but is so often applied to local elevations that it seems best to refer to them here. There is obviously no fixed standard of height as between a mountain and a hill. As

Fig. 137.—Punch bowl, Oahu. Photograph by Libbey.

we have seen, a worn-out mountain country is hilly in form, but mountainous in structure. A hill may consist of a pyramid of horizontal beds left by surrounding erosion. Such isolated masses may be found in the Alleghany plateau of New York, though most of the plateau is made up of long hill ranges with alternating valleys. Masses of volcanic or Plutonic rock, which resist erosion but are worn to moderate altitudes, form many hills. The dunes furnish another class, due to the action of the winds. All these have been sufficiently described for our present purpose.

255. **Glacial hills.**—These must here be briefly described. Like dunes, they are hills of accumulation rather than survivals of erosion. We here refer to the glacial forms which were left by the great ice invasion, which are in much greater variety than those of the Swiss or other valley glaciers. The typical moraine is an irregular aggregate of rough and often bowldery hills, frequently forming a belt of some width. The slopes may be steep or gentle, and the height may vary from a few feet to more than 1,000 in exceptional cases. A promiscuous group of steep, rounded knolls, or short, interlocking ridges and knolls, built of gravel and sand, with beds often highly inclined, receives the name of kames. The inclination of the beds is not due to uplift, but either marks the plane of deposition, or a subsidence due to the removal of supporting foundations of retaining walls of ice, by melting. Kames are themselves morainic structures, in whose formation the waters of the melting glacier take a large part. A linear or serpentine ridge, formed of material similarly stratified, is called an esker. These occur in New England and some other glaciated regions. Their height varies much, even in a single example, often ranging from 25 to 100 feet. The side slopes commonly have angles of 25° to 30°, and the crests may be barely wide enough for a road, for which they are not infrequently used. They follow the direction

Fig. 138.—Kame hills, Mendon Ponds, Monroe County, N. Y. Photograph by H. L. Fairchild.

of the former ice movement, and were probably made by heavily loaded streams flowing in subglacial tunnels, with formation of the side slopes as the melting of the ice allowed the materials to spread.

The drumlin is an elliptical hill, whose longitudinal profile is a smooth curve, and whose cross section may show a rounded or somewhat sharpened crest. Drumlins occur in eastern Massachusetts, western New York, southern Wisconsin, and other places, and are masses of till or

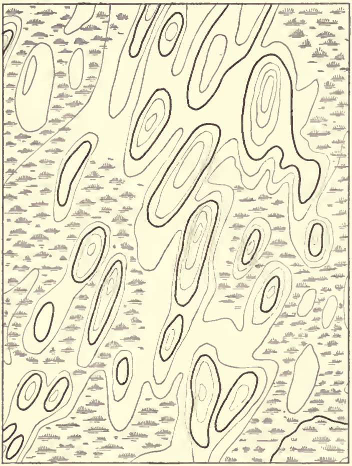


Fig. 139.—Drumlins with marsh lands, near Sun Prairie, Wis. Contour interval 20 feet.

bowlder clay, compressed and molded by overriding ice. Their longer axes coincide with the direction of ice movement.

The movement of a glacial sheet across and over hills previously formed subaërially, tends to reduce inequalities,

Fig. 140.—Drumlin, Groton, Mass. Photograph by G. H. Barton.

Fig. 141.—Drumlinoid glacial forms, Scotland.

to plane off ridges, and to fill up depressions, thus giving a smoothed and "linear" aspect to the topography. The sides of hills may present a fluted appearance, and single elongated hill masses are often given a form much like that of a drumlin. The drumlin is a hill of accumulation, while the drumlinoid (having the form of a drumlin) hill is a rock structure superficially modified by ice movement.

### *The Form of Valleys*

We have already studied the way in which a valley of erosion is made. The relation of valleys to the general elevation of a land surface will receive notice in a later section. We consider here the form, and first—

256. **The cross section, or profile of a valley.**—The chief elements in this are depth, width, and character of side slopes. The depth depends on the altitude of the land, the time for erosive work, the hardness of the beds, and the vigor of the erosive agent—river, glacier, or both. The Colorado Cañon is deep because the country is high, the stream is full, swift, and has been a long time at work. A deep valley could not be cut in the Atlantic coastal plain, because base level would soon be reached. The width of a valley depends likewise on its age, the power of the stream, and the destructibility of the rocks. A valley may widen indefinitely, even in a low country, if time enough is given.

The character of the side walls depends on a great variety of factors. They may be nearly or quite vertical because of overlying hard beds, as in the gorges of Niagara or Trenton, or by reason of dominant joint planes, as in Ausable Chasm. Rapid downcutting with slight general erosion, as in the case of the Grand Cañon of the Colorado, tends to this result, but it must be remembered that only the inner gorge is there bordered by giant precipices, while above the cañon is flaring, often several miles wide. Vertical walls may bound a narrow or a wide valley in the case of overlying hard beds and retreat by undercutting of the softer beds. As we climb the sides of some young valleys, we may come upon vertical sections alternating with benches or talus slopes due to a succession of hard and soft beds. A narrower inner valley may be cut beneath the bottom of an upper wide valley. The gorge of the Rhine is an example. Such a case is commonly due to a relatively sudden uplift of the land by which the stream grows in velocity, and applies its energy mainly to down-cutting. Spreading slopes of 25° or less are common as valleys approach maturity. Such slopes are abundant in the valleys of the Alleghany plateau. When a valley has passed maturity its inclinations are much more gentle and the alluvial deposits merge imperceptibly into the lower slopes. Whether the two sides in a valley profile are symmetrical or not depends largely on the structure of the rocks. A stream flowing along the strike of a monoclinal series of rocks would have one valley side steeper than the other. The same is true on opposite sides of a strong meander.

Deposits of waste, such as the talus, terraces, and various forms of glacial accumulations, greatly affect the cross profile of valleys.

257. **Longitudinal profile of valleys.**—The vertical element here is so small as compared with the length of a valley that it is not easy to form a mental picture of it, and it is impossible to delineate it by a diagram without gross exaggeration of the vertical scale. The Colorado, a very swift river, descends a little over a mile in flowing from Green River City to the Gulf of California. The Ohio-Mississippi River descends but 600 feet in covering an equal distance from Pittsburg to its mouth. In general the pitch of a valley bottom is large, either by cascades or torrents, in its beginnings among mountains, moderate in the long middle stretches, and almost zero toward the sea. Immature streams, which have not smoothed out the inequalities of their bed, may traverse almost level or moder-

ately descending platforms, with sudden plunges of cataract or rapid between them. In other words, we have a series of local and temporary base levels. Local blockades, especially by glacial accumulation, may turn a stream from its course at certain points, and thus render parts of a valley immature. We shall then have the profile of levels and plunges as above described. A typical case is the valley of the Genesee River. A rapid head-water section near the high sources in northern Pennsylvania is followed by a mature, moderately descending valley to Portage, N. Y. Then we have a gorge and three falls, with intermediate

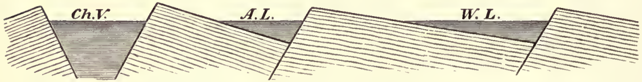



FIG. 142.—Lake basins due to faulting, Oregon. *W. L.*, Warner Lake; *A. L.*, Albert Lake; *Ch. V.*, Chemaukan Valley.

moderate descent, sluggish flow in an open valley to Rochester, two waterfalls and a gorge to Lake Ontario. The Mississippi, or the Missouri-Mississippi Valley, gives us head-water cataracts, long courses of moderate descent, and hundreds of miles of slight inclination. In general, the profile is a curve or a broken line, tending to become straight with maturity.

### *Lake Basins*

258. The geological work of lakes was outlined in Part I. The origin of the basin involves so many forces and structures that the subject was more conveniently reserved until now. We shall by no means name all the ways in which basins are formed, but for the most part only the principal methods. Fuller discussion may be found in Russell's Lakes of North America, or in Davis's Paper on the Classification of Lake Basins.* Lakes are signs of

* Proc. Boston Soc. Nat. Hist., 1882.

Fig. 143.—Lakes in glacial drift in a high mountain valley. Seven Lakes, Col.

topographic immaturity. They are transient features, commonly obliterated by filling with sediments or the cutting down of outlet channels. A lake may disappear by increasing dryness of climate, but in this case the basin would remain.

259. **Basins due to movements of the earth's crust.**—The upthrow or downthrow of crust blocks in faulting forms

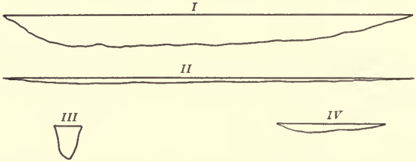



Fig. 144.—I, engineer's profile of Seneca Lake, longitudinal. II, longitudinal profile of Seneca Lake basin with vertical still much exaggerated. III, engineer's cross profile. IV, actual cross profile.

some basins between adjacent blocks. Here belong several lakes of the Great Basin and the Dead Sea (Fig. 142). Downthrow has made the latter, and evaporation keeps the water surface far below sea level, in spite of copious supplies from the Jordan. Other basins lie between folds and are formed by them. A broad fold is believed in part to account

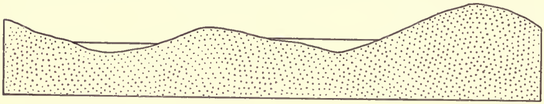


Fig. 145.—Section of kettle-hole ponds in a region of kames.

for Lake Superior. Here should probably be reckoned some Alpine lakes, though there is no agreement as to the relative efficiency of this cause and of glacial erosion. Valleys of erosion may be locally elevated or depressed by warping of the crust, thus turning parts of them into lake basins. Careful study is needed for each particular example, and definite knowledge may even then be hard to attain.

260. **Basins due to glacial action.**—These are of several sorts and very numerous. Many thousand exist in the United States. Some are due to blockades made by moraines left in valleys by the retreat of the glacier. The basin is thus a composite product of river erosion and glacial obstruction. Valleys may be filled with ground moraine throughout part of their course. To a filling of this sort south of Lake Ontario the Finger Lakes of western New York are in part due. Many small lakes lie in "ket-

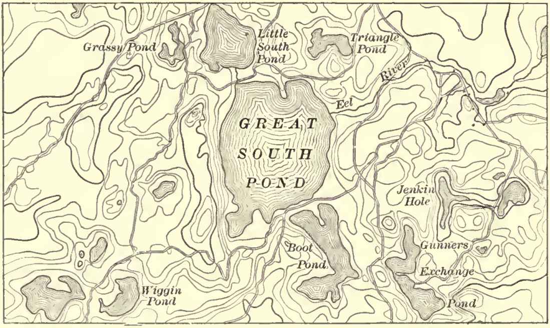



Fig. 146.—Glacial ponds south of Plymouth, Mass. Nearly 20 ponds in an area of 7 square miles.

tle-holes." These are found among moraines, and are believed to be due in some cases to a large block of ice which remained covered by *débris* for some time, but afterward melted out, with subsidence of the cover and the making of a basin. Other similar basins are simply due to the irregular deposition of moraines.

Most students of the subject believe that many basins have been dug out of the solid rock by glaciers, forming what is known as rock basins. It is not always easy to show the presence of a complete rock rim, or to distinguish a glacial basin from one made by folding. But it is hardly reasonable to doubt that many basins of the Adirondacks, of Scotland, and of the Alps have this origin. The deeper parts of the Finger Lake basins were almost certainly made in this manner. Very careful search for possible blockade should be made before a lake is affirmed to be in a rock basin.

261. **Lake basins of various origin.**—It will be sufficient to name several of the minor modes of formation. Lakes

Fig. 147.—Lake in glacial rock basin, Scotland.

are not infrequently due to volcanic action. Valleys are blockaded by lava, or water occupies an extinct crater or a subsidence basin, as is supposed for Crater Lake in Oregon.

Many lakes, as on the lower Mississippi, occupy old meanders, now cut off, or in mountain valleys are held in by *débris* cones, built by swift side torrents. Landslips blockade mountain valleys in a similar way. Inequalities of surface in great deltas produce shallow lakes. These are due to the shifting of the stream with its natural levees. Lake Pontchartrain is a noteworthy example. Small lakes are due to solution and sinking in limestone regions, and may even occupy shallow basins carved by the wind.

### *Shore Lines*

The principal facts belonging to an elementary study of these forms have been given in the chapter on the Ocean, and in the account of oscillations of the land. It remains here to restate two or three general principles.

262. **A rising shore line.**—This is commonly bordered by a strip of coastal lowland which, in times geologically recent, formed the marginal bottom of the sea. Inscribed on the gentle slopes of this lowland, or more likely on the base of the older highlands behind it, platforms and cliffs may be found which are old shore lines. The present shore is usually comparatively straight, or formed on a smooth curve, while the adjacent waters are shallow, and offshore sand reefs or low islands are made by wind and wave. After long rising a slight subsidence may have set in without much changing the conditions which have just been described. Such is the case with the present coast of New Jersey.

263. **A sinking shore line.**—Where sinking has long been in progress the water runs up into the land valleys, and the hills and mountains carved by erosive forces stand out into the sea as bold promontories, or form islands, washed and trimmed by the waves. Such a shore line is rough and jagged, the adjacent land topography has considerable relief, and the neighboring waters are often quite deep. Bold cliffs are formed by shore waves, abundant gravel beaches

FIG. 148.—An uplifted shore line with coastal plain. Davis and Curtis model.

are made in protected places, and bars and beaches of deposit are carried across bays and inlets. Behind these bars the waters fill with sediment from the land and with plant remains, and thus, by cutting away the projecting headlands and filling up the recesses, the shore line is straightened. This can only happen if there is a considerable pause in the movement of depression. If elevation follows long depression, the sea recedes, the shore lines form marked features on the seaward slopes of the land, and the land streams flow over and begin to cut away the filling of ancient bays and estuaries.

264. **Lake shores.**—The principles of shore formation are the same for lake and sea, save that tides are practically absent from the lake, and wave action is relatively light on small lakes. Even here, however, it is important. Lake shores are remarkably preserved on the mountain slopes about Great Salt Lake. This is the remnant of a former lake which rose 1,000 feet above the present water surface, and was two thirds as large as Lake Superior. By reason of growing aridity of the climate, the lake, which once had an outlet toward the Snake River, has dried away to its present area, and to its present depth of about 50 feet. The shore lines are magnificently preserved at several levels and are evident to any traveler in that region. The broad plains of Utah are the bottom of this ancient lake. Those who wish to know more of this remarkable chapter in the physical history of the West should consult Mr. G. K. Gilbert's report on Lake Bonneville, published by the United States Geological Survey.

Other conspicuous beaches occupy the slopes of the Red River Valley and girt all the Great Lakes at various levels. An account of these will be found in the chapter on the Glacial period.

Fig. 149.—A submerged shore line with embayed mountains.
Davis and Curtis model.

## B. Development of a Land Surface

### *General View*

265. We have now reviewed the chief elements that form parts of great land areas, in the light of their origin. It remains for us to see how these combine and what changes come over the land as a whole. Most land history begins with the spreading of the waste of older lands on the sea bottom. Then come uplifts, slow in progress, turning sea bottoms at once into low plains, or folding them into mountain ranges. Volcanic sheets are poured out here and there within or upon the rock strata, and cones are built high above the surface. All the destructive forces explained in Part I meantime attack the upraised masses, and carve forms which depend in part on the force at work, and in part upon the structures, small and great, described in Part II. Meantime, plains and mountains, hills and valleys, lakes and shore lines, will be seen everywhere in all kinds of form and combination. But the goal to which all things work is the destruction of the lands and the transfer of their materials to the sea.

### *Base Level and Cycles of Erosion*

266. A base level is a plane to which denudation must reduce a stably poised land mass, and below which denudation can not take place. This plane is that of the ocean surface. Rocks are ever being destroyed, and gravity, frosts, and streams are moving their waste downward and toward the ocean. The great river first cuts its bed close to the sea level, and we say that a portion of the valley is reduced to base level. It lacks a little of it, but the difference is so small that we neglect it. Gradually the valley widens, and the base-leveled strip extends up the stream toward the heart of the country. The same process begins with the lower and greater branches, while spurs of

highland lie between them. At length these ridges begin to be gashed by smaller and younger branches, which are to the river much as the twigs are to the trunk and main limbs. Each prominent ridge of land is buttressed by smaller ridges which run out from it between the streams that head near its crest. In time the head waters interlock, the crests sharpen and their materials begin to crumble, and the general level of the country begins to come down. After a time the inter-stream crests become rounded and softened, the valley bottoms wider, the relief of the district becomes moderate, then faint, and base level is approached. If the country be broad and high, inconceivably long periods of time will be used, but we must accustom the imagination as much as possible to the demand for vast duration in studying the history of our planet.

267. **Rate of down wear in earlier and later stages.**—While plateaus are elevated or mountains are young and lofty, the progress of denudation is rapid. Let one cross the plains of Holland and think of them as transferred, bit by bit, from the Alps; let him see the stupendous work of torrent and glacier in the valleys of Switzerland, and he must then appreciate the swift destruction of elevated lands. As relief grows less, the agents of destruction and carriage become less active, and when base level is nearly reached the progress becomes very slow.

268. **Youth, maturity, and old age.**—These terms scarcely need explanation, but are conveniently applied to land surfaces, showing various progress in down wear. High, sharp-crested mountains, with deep, narrow gorges and swift torrents, belong to topographic youth. Moderate altitudes, with a well-developed system of valleys, indicate maturity. Low reliefs, worn mountains, sluggish streams, and the absence of cliffs, waterfalls, rapids, and lakes, belong to the old age of the lands.

269. **Cycles.**—A cycle of erosion, or geographic cycle, is the period during which a country of considerable relief

is degraded to base level. Or the term may be applied to the whole series of topographic forms which appear and disappear during the time. But it is now important for the student to raise the question whether the land, as a continent or large island, ever remains without elevation or subsidence long enough for a cycle to be finished. This is certainly doubtful, but approximations to base level over large areas have been reached. Such a surface, nearly planed down to base level, but retaining some hills or mountains above the general surface, is called a peneplain (almost a plane). Plateaus like that of central New York, western New England, the Highlands of Scotland, and the uplands of the Rhine are believed to be anciently made peneplains, since uplifted and channeled by valleys. Any upland with an even sky line, such as may be seen along the mountain ridges of Pennsylvania, or in the regions above mentioned, is likely to have been produced in this manner.

### *The Evolution of Drainage*

270. Perhaps no geological force or physiographic form is capable of so much variety as a river and its valley. Many illustrations of this fact were given in the chapter on Rivers. We there studied the forms of land waste in valleys, waterfalls, revival by uplift, "drowning," by depression, and such accidents as glacial or volcanic blockade. In the preceding sections of the present chapter an account has been given of the form of valleys and of the more simple growth of a river system during the progress of denudation.

We must now state some further principles which show more fully the relation of rivers to the lands and to each other, and which especially present the river as a historical growth. This fact is emphasized in adopting the heading, Evolution of Drainage. The title Adjustment of Rivers is sometimes used. This refers to the important fact that streams and valleys take form and mutual arrangement from the rock masses on which they flow.

271. **Consequent streams.**—We have seen that the simplest and earliest kind of a land surface is a sea bottom which by elevation becomes a coastal plain. Down such a gentle incline new streams begin to flow. They follow the slope of the newly made land, and hence are called consequent streams. If, in the uplift, folding also takes place, the streams will flow one way or the other, along the inclining axis of the several folds. These also are consequent streams—that is, they take this course from the original form given to the uplifted land surface. The streams of the Atlantic coastal plain illustrate the former case. Similar to these are the streams of the Red River Valley in Minnesota and Dakota. The broad plains of this valley are a young lake bottom.

272. **Subsequent streams.**—Naturally the consequent streams do not occupy or drain the entire surface. As they establish themselves, blocks of country are left between them with imperfect drainage. Along belts of weak rocks branches develop, which sometimes come to great importance and revolutionize the river system of the region. These new rivers are naturally termed subsequent streams; they follow, or are secondary to, the original drainage. In very ancient times the streams of the southern Adirondack slopes continued southward across southern New York, and discharged into a sea that occupied parts of Pennsylvania, Ohio, and Virginia. West and East Canada Creeks, the Chenango, and upper Susquehanna are modern representatives of these ancient rivers. From Albany westward by Utica extends a belt of soft, shaly rocks. It was very easy for a branch of the Hudson to form and for its head waters to gnaw backward in strata so soft that a winter's frost will reduce fragments of them to their original mud. The Mohawk River is therefore a subsequent stream, and its trench is a subsequent valley.

273. **Antecedent streams.**—If the whole area occupied by a river is uplifted in a somewhat uniform way, the stream is simply revived and set to work again in a vigorous manner. If, however, a deformation is carried across its path, it may or may not continue in its old course. If the uplift is too swift for the down-cutting, the stream will be broken in two. Darwin found an old stream bed in South America, dry at the time of his visit, going down in opposite ways from a given point. But the uplift may be, and usually is, slow, and the stream, if powerful, may saw the growing mountain in twain as fast as it rises against it. The passage of the Green River through the heart of the Uintah Mountain ridge is usually given as an illustration, but this is questioned by some. The Kanawha River of the Appalachian region is another example.

274. **Longitudinal and transverse streams.**—Some streams in a mountain-built region flow in the direction of the folds and others flow across them. We will begin with an example—the rivers of central and eastern Pennsylvania. The West Branch of the Susquehanna flows with the line of folding from Lock Haven past Williamsport and is then transverse as far as Sunbury. The East Branch is longitudinal most of the way from Wilkesbarre to Sunbury. The branches unite there and flow southward as a transverse stream, through the great gap north of Harrisburg. Likewise the Schuylkill passes a gap below Pottsville, the Lehigh below Mauch Chunk, and the Delaware has its famous Water Gap near Stroudsburg. The upper waters of these streams, and of the Juniata as well, often flow for long distances in broad, open valleys, northeast or southwest, and then turn suddenly at right angles and pass the mountains by narrow gorges. Such an arrangement has been called a trellised system of drainage. It is thought to have had its origin when the region was a peneplain near sea level. The streams then disregarded the hard and soft masses beneath them, but as the land rose, being gently

inclined southward, the wide longitudinal valleys have been etched out of the soft rocks, and the vigorous transverse streams have kept pace in cutting away the hard ribs encountered as they have sunk their channels. By a series of changes, too elaborate to be explained here, longitudinal valleys often follow the eroded anticlinal belts. The Rhone is a longitudinal stream for most of its course above Martigny, and transverse from that point to Lake Geneva.

275. **Migration of divides.**—Territory may be gradually or suddenly won from one stream system to another. Such changes have occurred in great numbers, and a large field of study remains here for alert students.

If two streams head against each other, the upper waters of one may cut and carry away materials faster than those of the other. A greater supply of rain, softer rocks, or a steep slope and short distance to the sea, will produce this result. Materials will slide or be swept from the crest over into the basin of the effective stream, and the divide be pushed in the opposite direction. This may go on until the vigorous stream attaches to itself head-water tributaries of the other. These tributaries, instead of joining the new trunk at a natural angle, may resemble the barbs of a hook, and their former relation be detected in this way. The Mohawk is now acquiring territory at the expense of the Susquehanna in central New York. The whole or a part of a stream running along the strike of inclined beds will migrate in the direction of the dip. It should not be inferred from the above account that the crest of a divide must be sharp, with mountainous slopes, in order that effective migration may take place.

## C. Continents, Ocean Basins, and the Globe

276. **Continents.**—Each great body of land bearing this name is a combination of plains, plateaus, mountains, and other elevations, the entire surface being more or less channeled by valleys and overspread by a network of streams.

The height and area of the lands is small as compared with the depth and extent of the seas. But few mountains are above 20,000 feet in height, while important groups like those of the western United States and the Alps do not vary much from 15,000 feet in highest altitudes. Various estimates have been given for the average height of continents, supposing mountains to be leveled down and plains to be graded up. The estimates quoted by Dana are, in feet: North America, 2,000; South America, 1,750; Europe, 975; Asia, 2,880; Africa, probably about 2,000. The bulk of the greatest mountain ranges is small as compared with the general mass of continents.

The true bulk of the continental mass is, however, to be reckoned not from sea level, but from the sea bottom. The coastal plain often descends very gradually under the sea, and quite commonly there is a somewhat sharp descent from the 100-fathom line. This submerged platform is called the continental shelf, and is 50 to 100 miles wide along much of the border of eastern North America. A similar shelf surrounds the British Islands. They are thus structurally a part of the European continent, with which they once had land connection. The shelf lying on our eastern border was also a part of the Atlantic coastal plain in not distant geological times, and the Hudson, Delaware, Susquehanna, and other streams were some scores of miles longer at their seaward ends. The submerged valley of the Hudson is still traced by soundings out from Sandy Hook.

When we take up the thread of geological history we shall see that the great land masses have long held their present positions. Continents are therefore relatively permanent, and have grown through successive eras of deposit and uplift. Science has no sure or simple word to say as to the origin of continents, or at least as regards the uplift. Folding by contraction accounts well for the elevation of narrow mountain belts, but not clearly for lifting and sustaining such low and broad masses as form continents.

277. **Ocean basins.**—The oceans are to be regarded as parts of the primeval waters, somewhat isolated from each other by the formation of continents. Vast areas of the central seas are from 2,000 to 3,000 fathoms deep. Within these are smaller but important tracts having a depth of 3,000 to 4,000 fathoms. A few patches are known whose depth exceeds the last figure. Other great areas, especially in high latitudes north and south, range from 100 to 2,000 fathoms deep. The continental shelves and some arctic seas fall within 100 fathoms.

Widespread accumulation is the law of sea bottoms, and they therefore have little of the sharp relief characteristic of land surfaces. The exceptions to this are the volcanic and coral islands whose submerged slopes are of great height and often steep. Such a series of islands as the long Hawaiian group, with their submerged foundations, form an important range of mountains, rising from the profound depths of the Pacific. Following the axis of the central Atlantic in a zigzag course is a relatively broad ridge, lying 6,000 to 12,000 feet below the surface, bordered by the deepest parts of this division of marine waters.

278. **Form of the earth.**—This has long been known to be a sphere flattened at the poles. The amount of flattening is about 13 miles at each pole. It has been well observed that deformation of any circle in this proportion could not be detected by the eye. The form is such as would be assumed by a molten body cooling during continuous revolution. It is also known that the equator is not a circle, but is slightly elliptical. As in the case of the polar flattening, so with ocean basins and mountain heights, the variations from the form of the sphere are slight. Many models and diagrams are most misleading,

because depths, heights, and slopes of mountains and marginal sea bottoms are grossly exaggerated.

279. **Condition of the earth's interior.**—Several subjects in previous chapters have led naturally to this inquiry. Among these are volcanoes and earthquakes, oscillations, faulting, and folding. It has seemed best to defer any notice of theories to the present point. The hypothesis of a molten interior formerly had general acceptance. This was a natural result of a known increase of heat in deep mines and borings, and of the prevalence of eruptions of lava in past and present times. The word crust as applied to the outer part of the globe is a remnant from this belief. The term survives as a convenient designation for the rocks that are open to study, and carries no opinion about the masses that lie below. The theory of a liquid interior has been given up because of facts made known by astronomy and physics. Under the attraction which produces the tides, the earth behaves like a solid.

But, on the other hand, surface parts of the earth can not be entirely rigid, as is shown by folding, oscillation, and other movements of the crust. Hence some suppose that a relatively thin belt or zone of molten matter lies below the crust, but that the large inside mass is solid. In this view the crust is solid by cooling, and the nucleus by pressure, while the molten zone escapes hardening by either process. The subject must be left for the present, and perhaps always, in doubt.

It should be remembered that a body may be intensely heated and yet remain solid under great pressure. This is probably the condition of the greater part of the earth's inner mass. Crushing and folding may even relieve pressure at certain points, thus causing melting and volcanic eruptions. The density of the globe as a whole is about 5.5. This is nearly twice as great as that of the rocks of the crust. Some have supposed that owing to their weight there has been a great concentration of the heavier metals toward the center. Another view is that ordinary materials are so compressed by overlying matter as to have great specific gravity. For more light on this difficult question geology must continue to look to physics.

# PART III

# HISTORICAL GEOLOGY

## CHAPTER XV

### GENERAL PRINCIPLES

The history of the earth includes the geographical development of its surface and the story of its life. This twofold theme we shall now pursue as we might study the political, religious, literary, or industrial history of man. In geological as in human annals progress runs on different but parallel lines. In our field we find a physiographic and an organic evolution. Incidentally it will be profitable for us to study the chief economic products of the earth as we come to some of the periods of which they were formed. Such are coal, building materials, rock salt, and mineral oil.

### I. Materials of Geological History

280. As in ordinary history, so we find here a certain range of material. In the one field the student gathers from books, government records, newspapers of the time, from pictures and every kind of relics, and even from tradition. Likewise the geologist finds many sorts of facts, and counts no record unimportant. It is quite with reason that many historical societies include within the same walls a library and a museum of natural ob-

jects. For much that pertains to the story of the earth we must go to the astronomer and the physicist, but our chief reliance is upon rocks and the remains of living things.

We have already seen that rocks can tell us much about the times when they were made. We know whether they formed in deep water or along the shore, by organic or mechanical means, whether earth movements have taken place, with their nature and direction, and whether volcanic commotion has combined with more quiet displays in their origin.

Even more full and important is the revelation which we may gather from organic remains. We may know whether the ancient creatures lived on the land or in the water, and if the latter, whether they were denizens of fresh waters or of the sea. By knowing the habits of their modern relatives we decide whether they lived in the surf or in the deeper seas. With some limitation also ancient climates may thus be known. The occurrence of corals in the Northern States shows that currents of warm sea water once coursed in those regions, and the finding of palms in arctic latitudes demonstrates a yet more surprising revolution of climate.

281. **Fossils.**—According to a broad definition, a fossil is any organic form buried in the earth by natural causes. More commonly creatures thus inclosed within historic or recent times are not included, but no real distinction can be made. Any trace or impression of a living thing, such as a mold or a track, is also a fossil. The science which deals with fossils is Paleontology (Science of Ancient Beings). On the one hand it belongs to geology, on the other it is a part of zoölogy and botany. The field geologist generally submits his fossil specimens to a specialist in paleontology, and the figures and descriptions of organic remains form an important part of the literature of geology.

282. **Preservation of land forms.**—The land organisms suffer many chances of destruction. The oxygen of the atmosphere is ever causing decay. But there are some circumstances that favor preservation. Leaves, trunks, and entire plants may be covered from the air and saved from decomposition in swamps, or by burial in flood deposits, and in great marine deltas. Likewise the bodies or skeletons of men and the higher animals are preserved through miring in bogs, drowning in the passage of streams, or are sealed up beneath cave deposits. Worms and reptiles have left their trails and footprints in the muds of shores, to be covered and preserved to future ages. Insects are found entombed in the fine muds of ancient lakes, and sealed up in amber, a vegetable gum. Wood and even prehistoric human implements are sometimes found in the till and gravel deposited by the glacier or glacial waters. Twigs, leaves, and shells are often preserved in spring deposits, and several kinds of land shells have been found in fossil tree trunks in the coal rocks of Nova Scotia.

283. **Preservation of forms that live in water.**—It is in river and lake deposits, and particularly those of the sea, that the most complete record of life is found. Many marine creatures, indeed, are devoured as prey, or suffer decay, but in immense numbers they are buried and preserved, especially such as have hard parts, or skeletons of any kind. They often live in extensive colonies, and successive generations are buried under sheets of sediment as they form. Shells of pelagic creatures (those living at the surface of the sea) go down and mingle with those that always remain on the sea bottom. Likewise in ancient lake deposits, particularly in the western United States, a great variety of skeletons has been found, often of large size, of mammals, reptiles, and birds. Fishes also, and the beginnings of modern vegetation, are here found in a high degree of perfection.

284. **Fossilization.**—This term is applied to the changes which commonly take place in the composition or structure

of a plant or animal during its period of burial in the rocks. These changes are in all degrees. More recent fossils may have suffered no apparent modification. Others, such as shells of some geological antiquity, may have lost their luster without much internal change. The original materials may suffer all degrees of replacement. Thus a shell which originally was made of carbonate of lime may now consist of silica. The one mineral has been removed, particle by particle, by infiltrating waters, and the other has taken its place. The structure is often perfectly preserved, proving that the change is slow. This is illustrated in some specimens of fossil wood, which reveal the original woody structure, perfectly under the microscope, but are completely petrified.

Not infrequently an organism is more soluble than the inclosing rock. It thus disappears, leaving a cavity or mold, having its own shape. This mold may fill with other matter, producing a cast which will have the external form of the shell or organism, but none of its internal structure. We often find also casts of the interior of the form. These are sometimes made by mud drifting in between the two valves of a shell. Such specimens may be picked up on any beach, and are often found in very ancient rocks.

285. **Kinds of animals and plants most often preserved.**— It is plain that organisms having hard structures will be most sure to leave traces of their existence. Such are the bony skeletons of the vertebrates. The skeletons of ancient reptiles, birds, and fishes are preserved in great perfection. So also we find the carapace of crustacea, such as trilobites, crabs and lobsters, and the integuments and appendages of insects. Shells of univalve and bivalve mollusks are preserved in countless numbers in almost the oldest fossil-bearing rocks, likewise the hard parts of sea urchins, starfishes and their primitive kindred, the crinoids, also of corals and coral-like creatures. The shell-making

protozoa, particularly the foraminifera and radiolaria, are found fossil in abundance, as also woods, leaves, and fruits.

It must not be thought that the rocks bear no evidence of the more perishable creatures. Worms are known to go far back, by their trails and borings, and by the jaws of some species. Even the gossamerlike jellyfish has left its impressions most perfectly upon surfaces of fine-grained rocks, such as the lithographic limestones of Bavaria.

## II. The Making of a History

Having seen what kinds of facts are at hand, we must now seek to know how the geologist uses them to trace the chain of events in geological time. In the midst of seeming confusion, with many kinds of rocks lying everywhere, often disturbed, fragmentary, and hidden by soil and forest, how can a thread be traced through the tangle? This will appear in the chapters that follow, but a few principles had best now be fixed in mind.

286. **Younger rocks naturally overlie the older.**—This is the principle of superposition, and can be fully trusted in the undisturbed, sedimentary rocks of a limited district. As we have seen, in an area of great distortion, inversion may bring older sediments over those that are younger.

The principle of superposition does not help us to connect the history of one locality with that of a distant region. To a considerable degree rock strata can be traced across New York from the Hudson River to Lake Erie and the Niagara River. But even here there are great differences. Much greater are the differences between the rocks of New York and those of the same general age in the Mississippi Valley, or in the Rocky Mountains. Many strata are quite continuous across England, from the Channel to the North Sea. An English geologist can make out a history for his own country, as an American might for New York or Pennsylvania, but on the principle of superposition the two could make no comparison of their results with a view to tracing the history of the globe.

287. **The succession of living creatures.**—This is the most important fact in making a history of the earth. By much study and comparison during the past century, geologists have found that certain kinds of creatures lived in the time when very ancient rocks were made. Other kinds, beginning to have more resemblance to modern animals and plants, lived in what we may call the middle periods, and successive groups have led gradually on to the forms of to-day. Thus a kind of standard series from earliest to present types has been made out, so that now, if a new fossil is found, it can be referred to its place in the known series, and this settles the question of the relative age of the rocks that contained it.

Two or three examples may be given. The trilobite, as shown by wide observation, is practically confined to what is known as the Paleozoic era. If a specimen is found in place, this determines the rocks as of this time. But it is an era of immense duration. We find, however, that certain kinds of trilobites appear only in certain earlier or later parts of that era. Thus we narrow the age of the rocks to closer limits, and say, strata containing the trilobite called Paradoxides are Cambrian, and if they have Asaphus, they are Lower Silurian. Oysters are not older than Mesozoic, and particular kinds of oyster shells belong to various strata down to the present time. Of course, the standard scale is open to revision by fresh discoveries, as when, a few years ago, the present director of the United States Geological Survey found fish remains in older rocks than had before been thought to contain them. But we may trust the correctness of the succession as a whole. It is no man's invention, but has grown up out of the researches of thousands of observers in all parts of the world.

288. **Progress not uniform.**—In the early days of geology it was thought that the earth had been shaped mainly by

great catastrophes. This false idea gradually gave way to the doctrine of continual progress in past ages as at present. This is the true view, but must not be pushed too far. As there are epochs of revolution or of swift political or social unfolding, so there have been times of relatively swift geographic change. Great changes in geography cause also changes in the living forms. Barriers, such as mountains, are reared where none were before. Sea channels are closed and others opened, the direction of currents and the temperature of the waters are changed, clear waters are clouded with sediment, and variations of depth are caused. All these changes subject living forms to great strain, and they must migrate, modify their habits, or perish.

289. **Prophecy and reminiscence.**—No movement of history begins or ends abruptly. There were beginnings of a Rocky Mountain range long before the chief upheaval. This is especially true in the history of life. Fishes were once thought to begin and to become abundant in the Devonian period. But, as we have seen, their beginnings were far earlier. Reptiles were the sovereigns of Mesozoic lands and seas. But there were forerunners of the tribe in the Carboniferous times, and the reptiles of to-day are a minor group, a reminiscence of those ancient days. In other words, no age stands alone. It comes out of the past; it leads into the future; it marks a step in the long and never-resting evolution of the world.

290. **Faunas and floras.**—The assemblage of animals living at a particular time or age of the world's history is called the fauna of that period. We may also speak of the fauna of a particular group of rocks, or of a limited region, as the fauna of the Rocky Mountains, of the British Islands, of the deep seas. The Devonian fauna of New York embraces all the animals living in this area in the Devonian period, whose remains have been preserved in the rocks. Or we may confine the term to particular groups of animals,

such as the fish fauna, the molluscan fauna, the invertebrate fauna. The term flora is used in precisely the same manner of groups of plants.

291. **The life period of species and of the larger groups.**—The great types of animal life, except the vertebrate, are found in strata which are among the oldest sediments preserved to us. The backboned animals began later, but in high antiquity. But the minor groups have had a shorter history. They have come and gone; have thrived for a time and given way to others. Of the vertebrates, fishes, amphibians, reptiles, and mammals have one after another come into prominence, and all exist to-day, though some are of diminished importance. But within these classes many subdivisions have long been extinct. The larger branches of the organic tree usually live the longest—that is, classes and orders persist longer than genera and species, which are the included smaller groups, and less distinct from each other. As it has taken long to develop the fundamental types, so they have great vitality. But genera and species yield to modifying influences, and come and go.

These principles will be constantly used as we proceed, but a single illustration at this point may be useful. The Brachiopods are a highly important group throughout Paleozoic time. Hundreds of genera and species populated the ancient seas. Many appeared in the Cambrian period. Some of these (Lingula) have persisted with little change until to-day. Another group, the Spirifers, did not appear until the Upper Silurian period. They became very abundant, but were nearly extinct at the end of the Paleozoic era. But certain species of Spirifers are found only in a single stratum or small group of strata. They were offshoots of the main stock, which for unknown reasons ran their course and were soon extinct. It is also an important principle that a species once extinct has never been known to reappear.

292. **The geographical distribution of fossil species.**—As with existing animals and plants, so it is with those of former times. Some flourish in a narrow district, while others extend over a wide field. We often can not understand this, for one may appear to be as vigorous as the other. In the case of wide distribution, the form is believed to have developed in a single region, and thence gradually to have spread over land or sea. Such spreading is called migration. It is not meant that individuals change their home, except in certain cases, as of birds, but that successive generations widen the area occupied, or contract it on one side and extend it on the other, as when a forest is said to retreat before growing glacial conditions.

## III. Divisions of Geological Time

293. Limits put between epochs of history are always more or less arbitrary. The classical times merged into the mediæval, and the Middle Ages led gradually up to the modern centuries. Certain nations have been powerful, or certain social, political, or religious conditions have prevailed during a period. Or some great single event may be a suitable boundary, as when we use the American Revolution as marking the end of colonial days and the beginning of federal government in our own country.

In like manner the earth's history is one, but some special progress in land-making, or some type of living things, may distinguish a period of time. Thus the Devonian period is sometimes called the Age of Fishes. It is not meant that other creatures did not live in great abundance, but only that fishes were then first numerous, and were the highest animals of the time. Similarly the Mesozoic era is often called the Age of Reptiles. The great event which in America marks the passage from Paleozoic to Mesozoic time is the Appalachian revolution, by which a great chain of mountains was made in the east. Similar disturbances occurred in the European area at about the same time. We thus have a suitable landmark to separate two great areas. But we must also remember that, even then, quiet prevailed in many parts of the world. Change is always going on, with special events here and there. For the purpose of study we analyze the progress as best we can.

294. **Equivalent strata in regions remote from each other.**—These can only be determined by comparison of fossils. These need not be of the same species, and usually are not. But closely resembling species and genera are found—that is, the same orders, classes, and types. This does not show that the beds were formed at exactly the same time, but approximately, for time must have elapsed for the species or genera developing in one place to migrate to the others. The important principle for us to remember is, that beds with similar forms are contemporaneous in a general way. Thus the larger divisions of time are the same for all countries, but the smaller belong to a single country or district. The Upper Silurian period, for example, is well represented by the rocks of England and of New York. But in England the subdivisions of the Silurian are called Llandovery, Wenlock, and Ludlow, while in New York we speak of Medina, Clinton, Niagara, and Salina. The sets of subdivisions are only at some points alike, as regards their rocks and fossils. It will be seen that such subordinate divisions are usually named from places where the rocks are well displayed. The student should also notice that we may apply the name either to the rocks, or to the interval of time during which they were made, and during which their fossils were parts of living organisms.

295. **Tabular view of geological time.**—The names of the eras and periods as here given are nearly all in universal use. The same is true of the epochs of the Cenozoic era. The epochal names given for Mesozoic and Paleozoic belong to the American formations which represent those eras. The names of the eras refer to successive stages in the life

of the globe. Paleozoic means ancient life. Mesozoic refers to the mediæval era of organic history, but is in reality far later than this as regards the passage of time. The Cenozoic is the era of new or modern life.

The names of the periods have come into general use gradually and without similar harmony of meaning. For example, Carboniferous refers to a prominent mineral character of the deposits of the period; others, like Devonian, indicate a locality where the formations are well developed and were first studied; and some, as Tertiary, are the surviving remnants of numerical subdivisions which were much used in the early days of geology. Each name will be explained in the appropriate connection. In some textbooks the term period is used of certain shorter divisions of the Paleozoic era. Uniformity in the use of names is convenient, but the lack of it does not affect the reality of the time intervals or of the formations made while they were passing.

TABLE

| | |
|---|---|
| CENOZOIC ERA ....... | Quaternary Period, or Pleistocene Epoch. |
| | Tertiary Period. |
| MESOZOIC ERA ....... | Cretaceous Period. |
| | Jurassic Period. |
| | Triassic Period. |
| PALEOZOIC ERA ..... | Permian Period. |
| | Carboniferous Period. |
| | Devonian Period. |
| | Upper Silurian Period. |
| | Lower Silurian Period. |
| | Cambrian Period. |
| ARCHÆAN AND ALGONKIAN ERAS. | |

The student will find it well to become perfectly familiar at the outset with the names and order of the eras and periods, beginning with the oldest; also with epochs whose rocks may occur in his own State or region. For any full study of the epochs resort must be had to the larger textbooks and to geological reports.

## CHAPTER XVI

### ARCHÆAN AND ALGONKIAN ERAS

296. THE beginnings of the earth's history can never be known from record or relic. But the facts and comparisons afforded by astronomy save us from complete ignorance. What we may with considerable safety infer about the earliest condition of the globe is suggested by the Nebular Hypothesis.* This hypothesis, first proposed by Laplace, supposes that all the matter of the solar system was once a revolving mass of gases, having a diameter equal to that of the outermost planet's orbit. With the condensation that took place rings were thrown off like those of Saturn, and these rings broke up into planets with their satellites. The present sun is the central remnant of the original vast nebula. Many facts support the theory. Such are that more than two hundred bodies of our system have the same direction in their orbits, that their satellites pursue a like direction, which is the same taken by each individual body in rotating upon its axis; and that the sun is slowly contracting its diameter. Nebulæ marking various stages of cooling and condensation are believed to have been found in the celestial spaces.

If events took such a course, the earth must have been glowing and molten for a long period before an outer crust

* For a criticism of the Nebular Hypothesis, and a cogent and interesting presentation of an alternative meteoroidal theory, see article by T. C. Chamberlin, Hypotheses bearing on Climatic Changes.—*Journal of Geology*, October–November, 1897.

could be formed. But this condition must come at length, for the seething and fiery mass was constantly losing its heat into cold spaces. At last it would, at least in places, cease to glow, and lavalike crusts would form, only to be broken up from time to time and be reabsorbed, enacting on a gigantic scale what now transpires in the lava pools of Hawaiian craters. Even after a tolerably continuous crust had formed, volcanic outbursts must have been frequent and stupendous. Until cooling had well progressed, the gases which now make up the waters of the globe were included in the atmosphere, which would have been dense, dark, and of great thickness. It also contained great measures of carbon since stored in rocks, and rested with heavy weight upon the earth. During this stage no organic life was possible.

Gradually the crust became more stable, the gases condensed, and the primeval seas came into being. These may have been at first universal, but this we can not know. Wherever, by folding and upheaval, igneous rocks rose above the waters, lands were formed, rains would fall, streams would come into being, and the age-long processes of erosion and sedimentation would begin. If the waters of the sea were not still everywhere hot, they must often have been locally heated by volcanic outbursts. Such water, with a moist and hot atmosphere, would carry on chemical changes with intensity now unknown on the surface of the earth.

The time of a gaseous, molten, and glowing earth, before there was a solid crust, has been called by Dana the "Astral" æon or era. By the same author the term Azoic (without life) is applied to the time of the first crust, of high temperature, widespread waters, first emerging lands, and dense atmosphere. But as all subdivisions must be here vague and arbitrary, we only make such distinction as is possible between the earlier period which was barren of life and the later time from which a few fossils have been preserved. If beginnings seem dark and our knowledge doubtful, the student must remember that such is the case even where human history merges into the prehistoric but a few thousand years ago. From the entire pre-Christian era even a less body of fact is known than may be gathered from the single century now closing.

297. **Archæan Era.**—This term, which means ancient or primitive, is applied by some authors to all of pre-Paleozoic time and its rock formations. Most American geologists now restrict the word to the time of the earlier complex masses of highly crystalline rocks, many of them igneous, which are the oldest rocks preserved to us. It is not probable that any of these are parts of the first-formed crust. It is hardly possible that any part of that crust could survive. The Archæan rocks contain no fossils, but

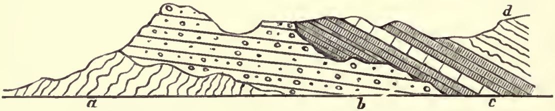



Fig. 150.—Diagrammatic section showing unconformity between Archæan and Algonkian (*a* and *b*) and between Algonkian and Paleozoic (*b* and *c d*).

they have suffered such prolonged and severe metamorphism and disturbance that organisms, if ever present, would have been destroyed. Doubtless many of these rocks were originally igneous, but some may have been sedimentary. No thickness can be assigned to them, but they underlie later rocks everywhere, and form the surface in irregular areas of small or large extent, where they have been uncovered by denudation.

297½. **Algonkian Era.**—The Algonkian rocks are younger than the Archæan, and are largely sedimentary. They lie unconformably on or against the Archæan. This shows that a very ancient land surface, roughened by erosion, received a cover of bedded rocks. But this later series is greatly metamorphosed, disturbed, and broken in its turn.

It gives a better clew to its origin by means of bedding planes, often preserved and containing, rarely indeed, some obscure fossils. The general distribution of pre-Paleozoic rocks, as a whole, is considered in the following section. Some of the important formations distinctly recognized as Algonkian are here noted. The Huronian rocks, held by Dana and others as a later division of the Archæan, are included in the Algonkian. The beds first known as Huronian occur to the north of Lake Huron, and consist (Van Hise) of comparatively little altered quartzites, slates, slate-conglomerates, cherts, and limestones, having a thickness of 18,000 feet. A great series of Algonkian rocks occurs in the Lake Superior region. Here belongs the Keweenawan formation, having a maximum thickness of 50,000 feet. Algonkian rocks occur in many parts of Canada and of the western United States. The subdivisions of the Algonkian in Minnesota are given as Keewatin, Animike, and Keweenawan, in ascending order. Taking the pre-Paleozoic rocks as a whole, they can only be compared in remote areas or different continents, by saying that they are all alike older than the earliest Paleozoic formations. These latter contain many fossils, and can be correlated even across the seas. Of the duration of the Archæan and Algonkian eras we can only make the general statement that it was immensely long. That the cooling of the surface would require vast time is clear from the slow rate of cooling of thin streams of lava flowing out upon a cold crust. We must add to this the long development of organic life, which probably took place before the Paleozoic era began.

298. **Areas of pre-Paleozoic rocks.**—By this expression we mean not actual outcrop, but regions whose bed rock, more or less covered by the soil, is of this age. More extensive than all others combined, in North America, is the great Canadian area extending from Labrador down upon the Great Lakes and thence northwestward to the Polar Sea. It forms a great V, which holds Hudson Bay between its arms.

In northern Michigan, Wisconsin, and the Adirondacks are its southern extensions. As seen above, a vast series of the later Algonkian formations is found in the Lake Superior district. The mining interests of this region have led to careful study of its rocks, but in much of North America, and especially of the other continents, no line has yet been drawn between Archæan and Algonkian. Pre-Paleozoic rocks form the most ancient axis of the Appalachian Mountain system, being found in the Highlands of New York and New Jersey, and continuing southwestward into Georgia. Other belts extend from New England to Nova Scotia and Newfoundland. Considerable belts are found at the heart of the Rocky Mountain range and in other parts of the mountain system of western North America. Patches appear in the Black Hills, in Missouri, and in central Texas. Everywhere these rocks have formed mountains, which are often worn off, as in the Highlands of the Hudson, to low altitudes. They therefore made land areas of considerable extent in these very ancient times. But we must not suppose that these lands, in form or size, were the same as the pre-Paleozoic areas of to-day. Submergence and elevation doubtless affected lands then as now, and there was ample time for many fluctuations during the eras.

The important fact to observe is, that the continent was roughly sketched in by these early lands. Lowlands now extend from the Gulf of Mexico to the Arctic Ocean, over a region which even then was swept only by shallow seas. This emphasizes yet again the very early origin of our continent.

299. **Pre-Paleozoic life.**—Here direct proof is meager, but several facts lead strongly to the belief that living creatures of lowly kinds dwelt in these ancient seas for a very long period. But few fossils, and these generally obscure, are found. This, however, is to be expected; for most of the primitive forms were probably soft and fragile, and metamorphism has gone on so long that it is wonderful to find any fossils remaining in these rocks. Beds of crystalline

limestone are common, and limestones are usually formed through the agency of living creatures. Beds of iron ore are extensive, and iron is usually, at least, concentrated by means of organic products. Graphite and shales, rich in carbon, point to the same conclusion. According to Dana, the plants were mainly algæ and microscopic fungi. Geology has no light to throw upon the beginnings of living matter. It only knows that organic history as a whole points to a progress from lower to higher through the long ages, and this argues strongly for a very long pre-Paleozoic era, during which the most lowly forms of plants and animals were leading the way toward the abundant life disclosed by the Paleozoic formations. That the previous records should have been nearly destroyed is, as we have seen, inevitable.

300. **Economic products of pre-Paleozoic rocks.**—The iron ores of northern and eastern New York and of New Jersey have long been worked. Likewise the iron of northern Michigan and of Missouri belongs to this era. In these rocks occur also tin, as in South Dakota, and Cornwall, England; much copper, gold, platinum, mica, graphite, and apatite (calcium phosphate, used as a fertilizer). The Keweenawan formation contains the rich copper deposits of northern Michigan. Building stones are found in abundance. Such areas are often important for their forests, their supplies of water, and the beauty of their scenery.

301. **Summary.**—Cooling, condensation, the formation of seas, atmosphere and early lands, are the features of the pre-Paleozoic eras. At some point, to the geologist unknown, life had its beginnings, and may have been abundant at the close of the time. If we had a full record, these eras could doubtless be separated into important divisions. Emphasis should be placed upon this point. Otherwise the student may gain the notion that these intervals were short, because we know so little about them, and because any account must therefore be brief. What we mean by long duration in geology will better appear as we proceed.

## CHAPTER XVII

### PALEOZOIC ERA

### Cambrian Period

302. **Introduction to Paleozoic history.**—We enter here upon an era whose records are comparatively full and easy to read. It is like passing from the traditions and moldering remains of our aboriginal Indian tribes to the abundant annals which we have of our colonial days. Even here much has been lost, but in one library or another every essential fact can probably be found. So it is with Paleozoic history. Over the broken and much modified, older rocks, lie the sandstones, shales, and limestones of the various Paleozoic periods, often packed with fossil remains. Sometimes, indeed, these rocks are also changed by metamorphism, and confused by dislocation, but we are still upon historic ground, and we may be sure that future study will only confirm the principles which we now hold.

Paleozoic time is very long. It is certainly to be reckoned in millions of years, and perhaps by tens of millions. In its beginning there were islands of earlier formed lands, roughly tracing the continents that were to be. At its close there were some large continental areas, and the interior or mediterranean seas were growing shallow, as in the region west of the Mississippi River. All through Paleozoic time land waste was accumulating in the seas south of the present Great Lake region and west of the Appalachian Mountain axis. By filling on the sea borders and by occasional upward oscillations the interior sea was shrinking in breadth and depth, until the entire eastern area of our country was dry land. The West, on the other hand, remained a region of sea and islands, a single Paleozoic land mass of importance developing where now is the Great Basin. The details of this geographic unfolding are reserved for the following chapters.

303. **Paleozoic life.**—In the earlier parts of the era all life was in the seas, and it was wholly invertebrate. Can we picture those early days? Barren enough the landscape must have appeared, had there been a human eye to see it. There may have been lands of bold height, for mountains were made in pre-Paleozoic time. But there was no green meadow or waving forest, no insect, flower, or bird. Over an uncarpeted surface denudation went on vigorously and muddy streams crossed the dark lands to the sea. In the sea no fishes swam and its monarchs were the trilobite and the orthoceras. The climate was warm and moist, the atmosphere heavy and full of clouds.

As we pass the middle of the era, land forms begin to come in, both animals and plants, but both were still subordinate to their kindred in the sea. Perhaps before the middle of the time we come upon the earliest traces of the great vertebrate group which in man was to dominate all, but as yet we have only a prophecy. When the era closed, however, there were wide lands, luxuriant forests, there were insects to awaken vibrations of the air, the amphibian had come and a few primitive reptiles, while fishes of ancient patterns swarmed in the seas. But of trees and flowers of modern kinds there were none. It was still a Paleozoic world.

304. **Relation of Paleozoic to earlier rocks.**—It is almost everywhere the relation of unconformity. Very general upheavals have taken place, and the waste was laid down to form the foundations of the Paleozoic systems. Sometimes the decayed surfaces of the older mass are still to be found when the newer beds are stripped away. They

are bits of ancient land, interesting relics of pre-Paleozoic geography.

305. **The Cambrian period—origin of the name.**—British formations of this period were especially studied by Sedgwick, of the University of Cambridge, between 1830 and 1860. They occur in Wales, and hence were named by him Cambrian, from the early name of that region. The Cambrian period has sometimes been counted as a subdivision of the period that follows, but fuller discoveries both in Europe and America have justified its claim to stand by itself.

306. **Epochs of the Cambrian period.**—In America these are as follows. The name of the earlier epoch is placed below to correspond with the relative position of the rocks:

| | |
|---|---|
| CAMBRIAN PERIOD..... | 3. Potsdam Epoch.<br>2. Acadian Epoch.<br>1. Georgian Epoch. |

The Georgian epoch is named from a typical series of its rocks near Georgia, Vt.; the second epoch bears the name of a Canadian locality near St. Johns, New Brunswick; and the third is taken from the town in northern New York about which its formations are finely displayed. The epochs and their rocks are also called Lower, Middle, and Upper Cambrian.

307. **Cambrian formations.**—The rocks of the Cambrian period consist of shales, sandstones, and conglomerates, with only occasional limestones. That they are commonly coarse, fragmental beds shows that they were laid down in shallow waters of the sea border, and accordingly we find them chiefly in narrow belts fringing the pre-Paleozoic areas in the North, the East, and the West. They also underlie the younger formations generally, and are sometimes revealed in such situations by profound erosion, as in the Grand Cañon of the Colorado. As may be inferred from the above, the surface areas of Cambrian rock in North

America are numerous, but individually of small extent. Only the worn edges are for the most part exposed. Thence they descend beneath the younger members of the several systems. That the exposed beds are sea-border formations


FIG. 151.—North American land areas in Cambrian time. 2 is shown as extended eastward. The dotted line is conjectural. The student must not take such a map as trustworthy in details. Compare similar map in Dana's Revised Text-book of Geology, p. 237, on which the Adirondack and other minor areas are shown.—After LE CONTE.

is also shown by the prevalence of ripple marks, rain prints, mud cracks, and the trails of marine animals upon their surfaces.

Cambrian rocks are found in Newfoundland, Nova Scotia, and New Brunswick. Rocks of this period occur along the borders of the pre-Paleozoic areas of New England and New York. At Georgia, Vt., is the typical lower Cambrian. This is adopted as the type section, by reason of the fossils, especially the trilobites, which are there found. At Braintree, Mass., are Middle Cambrian slates and conglomerates, famous for their fossils, particularly the trilobite Parodoxides. At other points, fossiliferous beds of this age are associated with metamorphic schists and marbles. The Potsdam (Upper Cambrian) sandstones of New York are among the best known of American Cambrian formations. They outcrop around the base of the Adirondacks, consisting of reddish shales and sandstones, from 60 to several hundred feet thick. Near Saratoga Springs is a Cambrian (Potsdam) limestone with many fossils. Cambrian strata continue along the Appalachian axis to Georgia. In Pennsylvania, in the South Mountain region, ancient lavas prove volcanic activity during the period. Other representatives are found in northern Michigan and Wisconsin. Cambrian rocks appear in the Black Hills, in the Rocky Mountains, are about 800 feet thick near the bottom of the Grand Cañon, and have an important development in the Great Basin in Nevada.

308. **Life in the Cambrian period.**—We have seen that the fossils of pre-Cambrian rocks are few and obscure, but from limestones and other deposits we infer that life was abundant. But in the Lower Cambrian alone we find at least 170 species described for North America. Before the end of the period all the great types were present, except vertebrates. We have here, however, not an abrupt appearance of living things, but only a more perfect record. The general unconformity between pre-Paleozoic and Paleozoic rocks shows widespread disturbance, and a general blurring of the record. Such disturbances of land and sea also would rapidly change the faunas of the time. Some species would die out, and others would be much modified.

Several classes of fossils now to be named will be described in the account of the Lower Silurian period, in which they appear in great perfection. No sure representatives of Protozoa have been discovered, though they doubtless existed, but, being small and fragile, are lost. A few sponges, graptolites, and corals are found. Echinoderms are represented by Cystids, a less perfect relative of the ancient Crinoids. Bivalve and univalve mollusks are not

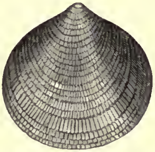


Fig. 152.—Dicellomus, a Cambrian Brachiopod.

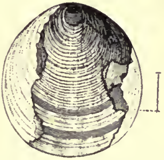


Fig. 153.—Lingulella cælata, dorsal valve, enlarged. Lower Cambrian.—After Walcott.

uncommon, but are few as compared with their numbers in the following period. Of creatures with shells, the Brachiopods are far the most important. They soon multiply to many hundreds of species and continue to be a great host in the seas throughout the Paleozoic era. A few leading genera of the Brachiopods should be carefully remembered as the student goes on. The most abundant Cambrian genus is Lingulella, with its related forms. The shell is thin and delicate, similar in size and shape to a small finger-nail, except that it is often pointed at the apex. While most Brachiopod shells are made of carbonate of lime, this consists of lime phosphate. In some rocks it is ebony-black in color, with a shining surface, which is marked by fine lines concentric with the beak or apex. Some slabs of Cambrian rock are almost covered with these shells. They have the great additional interest of having survived with little change to the present time, while other Brachiopods, much more abundant in a given period or place, have been for millions of years extinct. No good reason has ever been assigned for these vast differences in the vertical distribution or life period of different forms.

309. The most important creature in the Cambrian seas was the trilobite. It belongs to the class of crustacea, animals with outside skeletons, body rings, and jointed appendages. As the name implies, the body has three lobes or ridges, separated by two furrows, which are sometimes deep and sharp and sometimes obscure. Each lobe is divided into rings or segments (Fig. 154). Three parts of the body are also distinguished—a head, the abdomen, and the tail. There is great variety as to the distinctness of the lobes, and rings in head and tail. Sometimes the rings of the abdomen and tail, or the rear angles of the head shield, are prolonged into sharp spines. Prominent stalks on the head shield sometimes bear eyes, consisting of many lenses (see eye of Phacops rana, section 338), but in other cases the creatures were blind. In some species the segments moved freely upon each other, and the animal could roll itself together, concealing its under parts within. Many fossil specimens are found in this condition. Adult trilobites vary in length

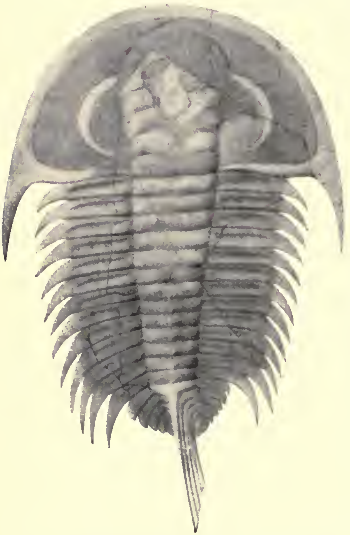


Fig. 154.—Olenellns (Mesonacis) Asaphoides. Lower Cambrian, Washiugton County, N. Y. —After Walcott.

from less than an inch to two feet. They are a Paleozoic group. We shall meet many forms, and find them of high importance as marking strata of different periods and epochs.

Over 50 species of trilobite, according to Walcott, have been found in the Lower Cambrian rocks of North America.

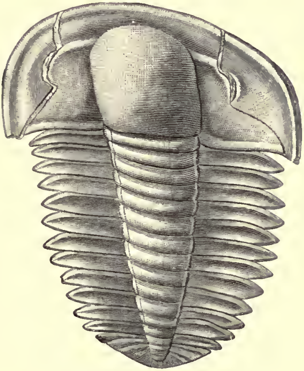


Fig. 155.—Protypus Hitchcocki.

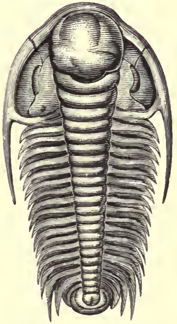


Fig. 156.—Paradoxides Harlani. ½ natural size.

Not only are the Cambrian trilobites peculiar to the period, but some genera are characteristic of the several epochs. Paradoxides Harlani has long been known from the Middle Cambrian rocks of Braintree, Mass., and specimens of it may be seen in the collection of the Boston Society of Natural History and in other museums.

Other crustaceans occur in Cambrian rocks, and tracks, sometimes obscure, made by crustaceans, mollusks, or worms. Some doubtful impressions also are referred to seaweeds, which, without much doubt, existed. But we have no record of any land plant or animal.

310. **North American geography in the Cambrian period.**— According to Walcott, there was extensive land in the cen-

tral portions of the United States in the Georgian or Lower Cambrian epoch. Hence deposits of that age could not be formed in that region. During the later Cambrian, however, sinking went on and the sea crept northward over the interior of our continent. In harmony with this we find thick masses of coarse, fragmental rock on the borders of the ancient lands lying around this central area, and these

Fig. 157.—Ripple-marked Potsdam sandstone with trilobite trails, Port Henry, N. Y. (In New York State Museum.)

beds could only have gained such thickness through continental subsidence. But, notwithstanding subsidence, the interior sea remained shallow in the later Cambrian times, showing that virtually a great continental mass lay where

North America now is. This testifies to the great antiquity and permanence of our continent. That the actual land of Cambrian time was extensive and somewhat bold is shown both by the abundance and the coarseness of the marine sediments of the period.

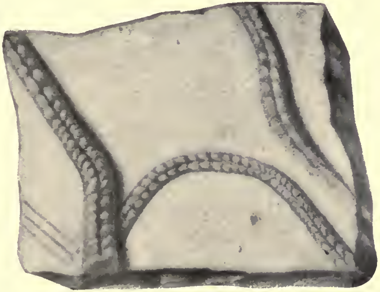


FIG. 158.—Trail of animal. Upper Cambrian of Arizona.—After WALCOTT.

311. **Economic products of Cambrian formations.**—The red sandstones of Lake Superior, and the red, chocolate, and cream-colored sandstones of the Potsdam epoch in New York are much used for building. The latter are particularly durable, being compacted by a siliceous cement, and have shown a maximum crushing weight of 42,000 pounds. They will also endure a degree of heat which is destructive to marbles and granite. Cambrian rock is also quarried for marble at Swanton, Vt.

# CHAPTER XVIII

## PALEOZOIC ERA

### Lower Silurian Period *

312. **Name and subdivisions.**—The name of the period is taken from an ancient British tribe, the Silures, and was first used by the English geologist, Murchison, who studied this system of formations. The epochs are as follows :

| | |
|---|---|
| Lower Silurian Period. | 5. Hudson Epoch (Lorraine beds). |
| | 4. Utica Epoch. |
| | 3. Trenton Epoch. |
| | 2. Chazy Epoch. |
| | 1. Calciferous Epoch (Beekmantown limestone). |

Before and after the year 1840 several eminent geologists made a survey of the State of New York. They found a full and generally undisturbed succession of Paleozoic formations, and usually applied to them the names of localities where they were well displayed. Thus we have what has become known as the New York series of rocks. This has been adopted as a standard of comparison for all the Paleozoic formations of North America. Thus the Trenton limestone is found typically exposed in the great gorge at Trenton Falls, N. Y. The time during which the rock was made is the Trenton epoch. If a formation of the same relative age is found in the West or South, it is said to be of Trenton age. It may also have a local designation, and may consist of shale or sandstone

* By some authors this period is called Ordovician.

rather than limestone. It must, however, have the same position as the Trenton in the geological column, as shown by its fossils and by its general relations. By attention to this principle the student may avoid the feeling of confusion which often attends the occurrence of so many local names of formations.

313. **General character of the Lower Silurian period.**—We have seen that in Cambrian times the rocks made in the regions now accessible to us were mainly coarse and often of shore formation. The student must not forget that in the deep seas of that, as of all periods, fine muds were accumulating. In the Lower Silurian, however, the region of the growing continent was largely covered by waters of some depth, often clear and free from land waste, in which Brachiopods, corals, and Crinoids could flourish, and contribute their remains toward the making of limestones. Hence the Lower Silurian was largely a limestone-making period. This does not mean that the waters had great depth, which is not necessary for the accumulation of ordinary limestones. Only moderate subsidence was needed, and this, as we saw, was in progress in the later Cambrian. At the close of the period there were mountain-building in the East, and extensive additions to the growing continent.

314. **Epochs of the Lower Silurian period.**—The earliest is the Calciferous, and its rocks overlie the Upper Cambrian. In this case the name is not a local one, but was applied in New York to a sandy rock containing much lime. A typical locality for the rocks and fossils of this epoch is at Beekmantown, N. Y. The weathering away of the lime is apt to leave a surface roughened by the outstanding grains of quartz. Middleville and other calciferous localities in New York are famous for the perfection of their quartz crystals. Equivalents of the Calciferous, as shown by fossils, are found in Newfoundland, also southward to Tennessee and westward to Iowa and Minnesota.

The Chazy epoch is represented by limestones in the St. Lawrence region, and in northeastern New York, where a village furnishes the name. Purer limestones following—that is, overlying—the Calciferous beds, show deepening and clearing of the waters. The most important epoch of the Lower Silurian is the Trenton. It will help the student to clearer ideas of the growth of the continent if we state more fully the distribution of the Trenton limestones. Over 300 feet of them are exposed in the gorge of the West Canada Creek at Trenton Falls. They are shaly, thin-bedded, and rich in fossils, except a heavy crystalline stratum at the top. In the vicinity and along the Black River thin strata of the dark Black River limestone, and the light-gray Birdseye (Lowville) limestone, form the base of the Trenton. The formation outcrops along the Mohawk Valley, and more or less about the base of the Adirondack mass. It is well developed in the St. Lawrence region, and extends up an ancient marine gulf to Ottawa. A belt of Trenton stretches along the north shore of Lake Ontario. Westward, it is found in Wisconsin, Minnesota, Iowa, and Missouri. Returning to New York, we find it southward along the Appalachian axis. It is brought to light by extensive erosion, and forms the floor of the great anticlinal valleys, like the Nittany in central Pennsylvania, and is several hundred feet thick in Tennessee. Borings for gas and oil have shown that the Trenton extensively underlies the younger formations in central and western New York, and in large areas of Ohio and Indiana. Thus we can picture the interior sea, teeming with organic life which covered its bottoms with a mantle of calcareous mud. The borders of the sea lay north and east, near the present lines of outcrop of Trenton, Cambrian, and pre-Paleozoic. Coarser rocks, which must have been made along the actual shores of the Trenton sea, have been destroyed by the denuding forces which have been so long at work. These would have carried the real shore line in central New York, for example, farther to the northeast on the Adirondack slopes. Rocks referred to the Trenton epoch occur in various parts of the Rocky Mountain region, in the Great Basin, and in arctic latitudes.

In New York especially the waters began to be clouded with fine materials which settled over the Trenton muds and formed a thin-bedded black shale from 100 to 700 feet thick. The time during which this deposit was in progress is called the Utica epoch, and the rock itself the Utica shale, from the city of that name. The shale is very carbonaceous. This is due to the presence of much organic matter and gives to the rock its dark color. The Utica shales shade gradually up in central New York into the coarser, often sandy and widely distributed, beds of the Hudson* epoch, so called from extensive displays along the Hudson River. Thus, as we had deeper and clearer waters in the earlier part of the Lower Silurian period, so now the change is in the reverse order. We must, however, now notice the important fact that the Hudson rocks of the old eastern shore lines are sandy and thick, while in the remote offshore regions of the Ohio and Mississippi Valleys they are thinner and are limestones. This is a general principle which applies to many epochs and their deposits, and is a conspicuous illustration of the manner in which rocks tell the story of ancient geography. About Cincinnati 700 feet of shaly limestones of Hudson age contain abundant fossils. According to Dana, between 3,000 and 4,000 feet of Utica and Hudson shales were penetrated by a boring near Albany, N. Y.

* According to Clarke and Schuchert, "it is becoming increasingly evident that the great mass of shale in the Mohawk and Hudson River Valleys, which was designated at an early date by this term, is resolvable into horizons extending from the Middle Trenton to and including the Lorraine beds." The term Lorraine is taken from a series of shales in Jefferson County, N. Y.

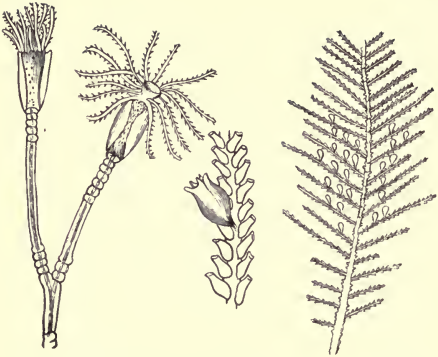


FIG. 159.—Living Hydrozoa, to illustrate the ancient graptolites.

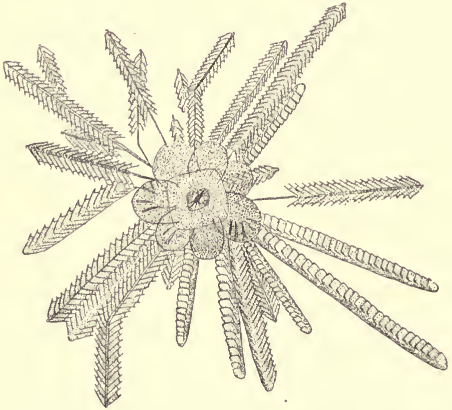


FIG. 160.—Diplograptus quadrimucronatus. Complete free-swimming colony, Utica shale, Herkimer County, N. Y.—RUEDEMANN, in New York Reports.

## LIFE IN THE LOWER SILURIAN PERIOD

Several types which appear in moderate numbers in Cambrian times now become abundant. This is particularly the case with corals, Crinoids, and mollusks. Before the end of the period we shall chronicle the entrance of air-breathing creatures and backboned animals. We must here also briefly describe certain kinds of fossils which first become plentiful in Lower Silurian rocks.

315. **Graptolites.**—These fossils are found in Cambrian rocks, but are abundant in the Lower Silurian. They are

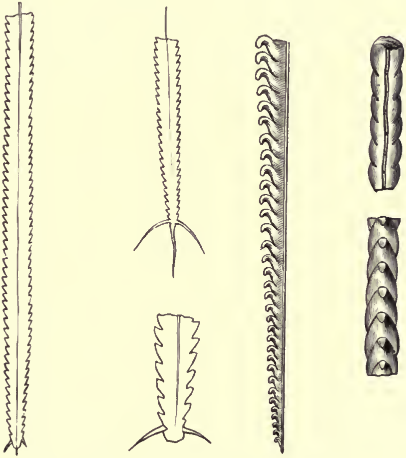


FIG. 161.—Diplograptus and Monograptus.

usually seen as long, narrow, sometimes branching impressions on the bedding surfaces, and hence receive their name, which means pen stones, from their resemblance to a quill pen. On one or both sides of this axis or stem are notches or cells, each one of which was occupied by an individual of the little community, all of which had a common body in a central tube. Some of the forms are shown in Fig. 161. There were many species, and they were often characteristic of a series of rocks. Their greatest development is Lower Silurian, though they continue through the next period.

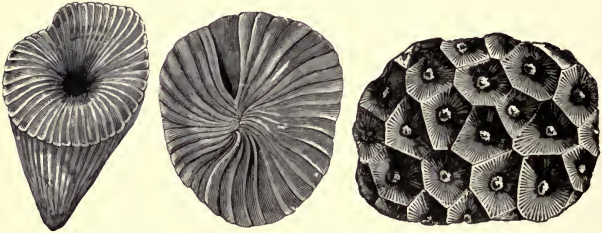


Fig. 162.—Cup corals. Single polyps and a community. (These are Upper Silurian forms.)

316. **Corals.**—These important rock-makers also occur in Cambrian formations, but are first abundant here. The Paleozoic corals were of a considerably different pattern from the modern forms, although all have a general resemblance. The principal kinds were three—the Cup corals, the Favosite or Honeycomb corals, and the Halysite or Chain corals. In the first the cups or polyps were solitary

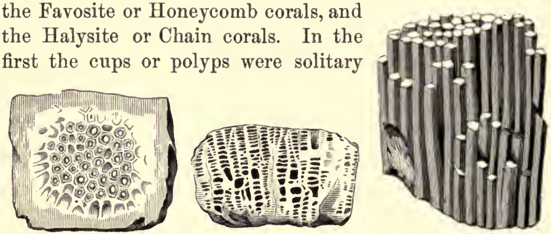


Fig. 163.—Favosite coral; cross section, vertical section, and general view.

or in groups or bundles, and often large, even to a foot in length in extreme cases, and such having diameters of two or three inches. The inner space may be divided by radial partitions, horizontal floors, or by irregular partitions forming a mass of small cells. In Favosites the polyps are small and polygonal, and massed together in great numbers. Their arrangement in Halysites is very graceful, and is sufficiently shown in the figure (Fig. 178). The corals as a whole show that the seas in which coralline limestone was making were warm and of moderate depth. Unlike graptolites, the corals grow in importance in the succeeding period.

317. **Crinoids.**—These are so named from their likeness to a lily, and are the ancient kindred of the existing starfishes and sea urchins, though a few of them have been found living to-day, being dredged from the ocean bottom. In Paleozoic times they were very abundant. They possess great symmetry and grace of form, and contributed largely to the making of some limestones. A typical Crinoid has a spherical, pear-shaped or urn-shaped case, called the calyx,

Fig. 164.—Crinoid, showing arms and upper part of stem.

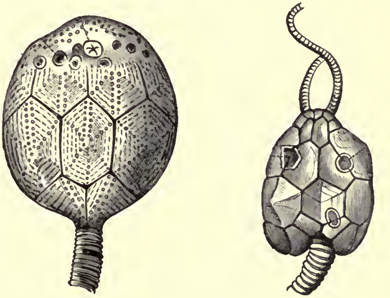


Fig. 165.—Cystids, one showing two rudimentary arms.

which is made of hard plates and holds the vital parts. Rising in a circle above this, around a central mouth, are several arms, with delicate branches, giving them the appearance of plumes. By these the water was stirred and food conveyed to the mouth. The whole was mounted upon a stem, which was attached (not rooted) at the sea bottom. The stem varied from a few inches to several feet in length, and was made of a column of joints like small coins, firmly bound together, but flexible as a whole Forests of these graceful organisms must have covered many sea bottoms. A more primitive kind has a short stem or none at all, plates less symmetrically arranged, and no branching arms. These are known as Cystids, and came to their height during Lower Silurian time. Another sort are known as Blastoids, or bud-formed. They are indeed bud-shaped, having a fivefold petalloid arrangement. These, like the typical Crinoids, culminated later.

318. **Brachiopods.**—We have seen that these forms were numerous in Cambrian times, but they become exceedingly abundant in the Lower Silurian period. The Trenton waters teemed with them, as some mollusks populate the seas of to-day. Among the most noteworthy we name the Lingula, already described; the Discina, a disklike shell of similar small size, though larger in later periods; the Rhynchotrema; the Orthis, a shell with a straight hinge,

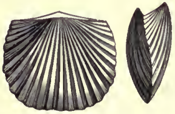


Fig. 166.
Orthis Davidsonia.

Fig. 167.—Rhynchotrema capax. Hudson River group, Frankfort, Ky.

and having first and last many species; and the Leptæna. *Orthis testudinaria*, or the shield-shaped Orthis, may be singled out as especially common in Trenton seas.

319. **Mollusks.**—These animals came to great numbers in Lower Silurian times, in all their classes, bivalves, univalves, and chambered shells. Bellerophon, a trumpet-

shaped Gastropod, and Pleurotomaria, a low-coiled shell of the same class, are common in the Trenton rocks. The most striking addition to the molluskan fauna is the vast number of Cephalopods, ancestors of the Nautilus of today. A few, like the Nautilus, are coiled, some are simply curved, but the majority

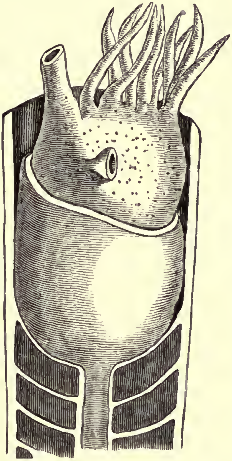


FIG. 168.—Orthoceras, restored, showing position of the animal, the chambers, and siphuncle.

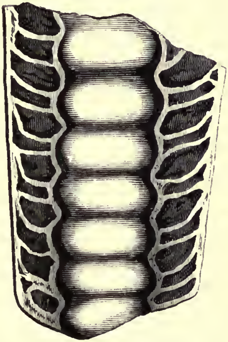


FIG. 169.—Ormoceras, showing chambers and large siphuncle.

were straight and many belong to the genus Orthoceras, from words meaning straight horn. Some had the diameter of one's finger and were a few inches in length, gently tapering back from the open end where the animal resided. Others were several feet long and a number of inches in diameter, up to a foot in some cases, with extreme lengths of 10 to 12 feet. Here first, then, we meet with animals comparing in size with creatures of modern seas. Like the Nautilus, these ancient shelled Cephalopods had their shells divided into compartments by cross partitions, through all of which from the animal backward ran a small tube called the siphuncle. Good specimens often show siphuncle and partitions. The latter were set on a simple curve. This should be remembered, since in later periods we find them complicated in high degree, illustrating a great principle in the evolution of life on the earth. A peculiar class of mollusk, classed as a Pteropod, is exemplified in Tren-

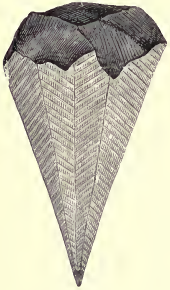


FIG. 170.—Conularia.

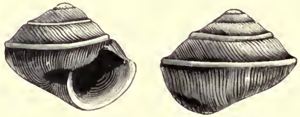


FIG. 171.—Pleurotomaria, a low-coiled Gastropod.

ton rocks by Conularia, a four-sided pyramidal shell of considerable size. The reference of Conularia to the Pteropods is, however, doubted by some authorities.

320. **Crustacea.**—The Trilobites, so numerous in the Cambrian, are still increasing in importance. The great genera are as follows: Isotelus, which had massive head and tail pieces, eight segments in the abdomen, an elliptical general outline, and was large, up to eight inches or more in length; Calymene, smaller, two inches long or less, distinctly segmented in abdomen, tail, and middle lobe of the head, and often found rolled up. Very perfect specimens occur in the Trenton of New York and the Hudson rocks of Cincinnati; Trinucleus, small, with two head spines extending far back, and a prominently lobed head; Triarthrus Becki, a characteristic and very abundant species of the Utica shale, two inches in greatest

FIG. 172.—Murchisonia, a high-coiled Gastropod.

length, each segment of the middle lobe bearing a short spine. Near Rome, N. Y., specimens have been found revealing the under structures and jointed appendages of the Trilobite, as shown in Fig. 176. A series of the embryonic forms of this species has also been found.

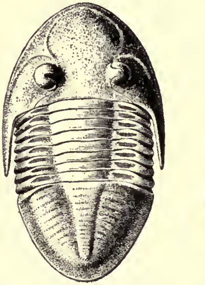


Fig. 173.—Isotelus maximus. (Asaphus platycephalus.)

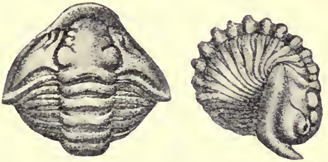


Fig. 174.—Calymene, enrolled specimen; top and side view. From Lower Silurian of Ohio.

Lower Silurian rocks also contain Leperditia, a small crustacean beginning in the Cambrian, and also the earliest known examples of the Barnacle and Eurypterus.

321. **Insects and fishes.**—The earliest known insect is reported from the Lower Silurian of Europe, but the first known American example is Upper Silurian. In 1892 the present director of the Government Geological Survey found fragments of fishes in rocks of Trenton age near Cañon City, Col. Thus these forms began much earlier than had been supposed. In the same way fresh discoveries may increase the known antiquity of many other branches of the animal kingdom.

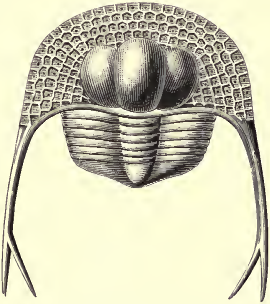


Fig. 175.—Trilobite, Trinucleus; short body, long spines, prominent lobes of the head. Enlarged.

322. **Plants.**—A land plant is also reported from the Lower Silurian of Great Britain, though considered doubt-

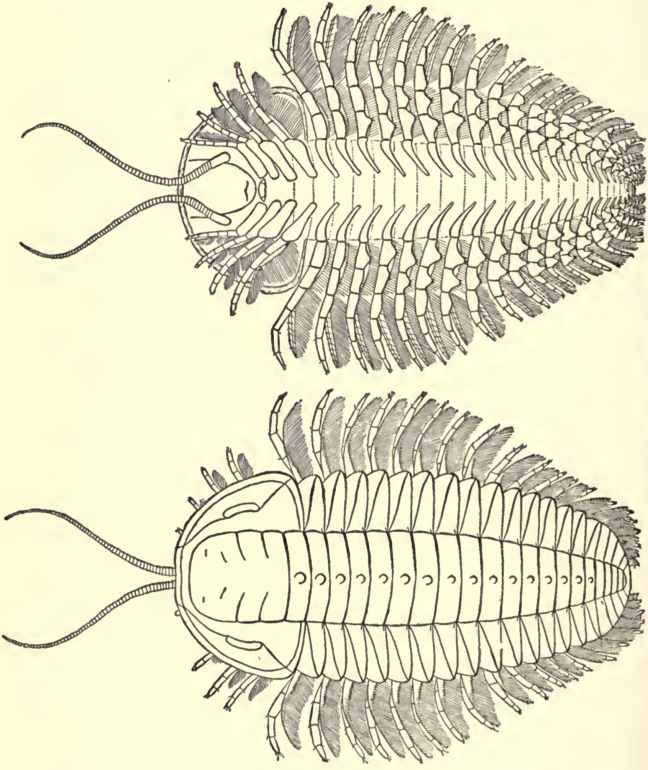


Fig. 176.—Trilobite, Triarthrus, restored and enlarged, showing jointed appendages.

ful by some. The life of Lower Silurian times was abundant both in variety and in number of individuals. The number of species of Brachiopods, Mollusks, and Trilobites aggregated several thousands, and beds of limestone many feet thick are often almost wholly made up of two or three kinds of shells.

323. **Economic products of Lower Silurian rocks.**—The Trenton limestone is often locally used, as in New York State, for building. A black fine-grained bed of the same in eastern New York takes a high polish, and has been known as Glens Falls "marble." Some of the true marbles of the Green Mountains, and of the red and variegated marbles of Tennessee, are Lower Silurian. Much of the Trenton is also burned for quicklime. In northern Illinois we have the Galena limestone of Trenton or Utica age as the source of lead ores. In Ohio, Indiana, and central New York the Trenton limestone is the great source of the supplies of natural gas. In northern Ohio and Indiana the Trenton is reached at a depth of a little more than 1,000 feet. The gas has been produced by decomposition of the original organic matter of the rocks; it is stored, according to Orton, in beds of Trenton which have become porous through secondary changes, and is held there, until released by borings, by an overlying mass of fine close-textured Utica shale. Pressures of 300 to 600 pounds per square inch have been

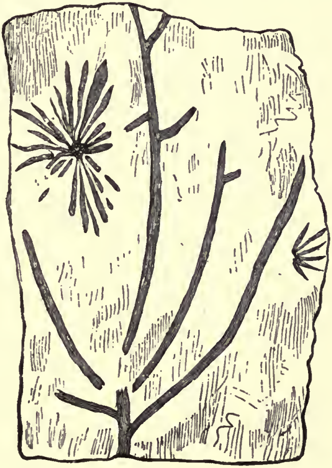


FIG. 177.—A Rhizocarp, a marine plant of the Lower Silurian period.

observed, but much greater than this near Baldwinsville, N. Y., where pressures of 1,400 pounds to the inch have been measured.

324. **Soils.**—The making of these is doubtless the most important economic use of Lower Silurian limestones, and of the highly calcareous and carbonaceous shales of the Utica epoch. The productiveness and prosperity of the "Blue Grass Region" of Kentucky are due to its substructure of Trenton limestone, while in regions like New York, the Trenton of the Adirondack regions, and north of Lake Ontario, has been widely mixed with the soils by southward movements of glacial currents.

325. **Close of the Lower Silurian period.**—In eastern North America we now have important geological changes. Much of New England east of the Adirondacks and New York Highlands had been covered by the sea, receiving sediments during various Lower Silurian epochs. In the vicinity of Albany, north and south, there was free passage into the waters from the interior sea that extended over central New York and thence westward and southward. As the period was closing, the thick sea border sediments of the New England region were crumpled and uplifted to form the Taconic Range, including the Green Mountains of Vermont. The disturbance was felt as far north as Nova Scotia and southward to Virginia. We know the age of the range because Lower Silurian beds were folded in to form it, and Upper Silurian beds only reach eastward to the base of the mountains, and lie unconformably on their upturned edges in eastern New York. Accordingly, several series of Upper Silurian rocks thin out and disappear in central New York going eastward. Thus we see that some of the marbles and crystalline schists of western New England are of the same age as the unchanged Trenton of New York or the Mississippi Valley. In southern Ohio and eastern Kentucky the strata are bent into a broad, low arch, whose axis runs in a nearly north and south direc-

tion. Some observers believe that this arch is due to the mountain-making pressures with which the Lower Silurian Period closed. If, however, an island was thus formed, it was later submerged, for younger formations were deposited in the region. These younger beds have for the most part been removed by denuding forces, and thus we now find interesting exposures of Lower Silurian rocks, rich in fossils, about Cincinnati.

# CHAPTER XIX

## PALEOZOIC ERA

### Upper Silurian Period

The rocks of this period, as of the one before it, were studied by Murchison, and were named by him.

326. **Epochs of the Upper Silurian.**—The development of our continent was similar to its progress in Lower Silurian times. Five epochs are distinguished in the New York formations:

Upper Silurian Period.
- 5. Waterlime and Tentaculite Epoch (Rondout and Manlius).
- 4. Salina Epoch.
- 3. Niagara Epoch.
- 2. Clinton Epoch.
- 1. Medina Epoch.

The rocks of the Medina epoch are named from Medina, N. Y., and consist of sandstones and shales. They are several hundred feet thick in western New York, covering a belt on the south shore of Lake Ontario, and they form the lower part of the gorges of Niagara, and the Genesee at Rochester. They are not found westward beyond eastern Ohio. In central New York there are beds of building stone, known as the Oneida Conglomerate; and similar beds, the Shawangunk Grit, form the Shawangunk Mountains west of the Hudson. Medina sandstones are 1,800 feet thick in Pennsylvania, and their upturned and denuded edges form the great succession of mountain ridges which, in zigzag courses, inclose the valleys and overlook the lowlands. They continue to Virginia and Tennessee. More nearly than any series yet studied in this review, their outcrop represents the shore line of the interior sea. Hence we do not find them far away from the old shores, as, for example, in the central Mississippi region.

Overlying these, and outcropping south and west where undisturbed, are the rocks of the Clinton epoch. They are named from Clinton, N. Y., and extend westward to Wisconsin and southward to Tennessee. The thickness is from 80 to 1,000 feet, and the character variable—sandstones, greenish-gray shales, and a few limestones, with one or more thin beds of oölitic iron ore. As a rule they were laid down in shallow waters. They lie over the Medina and under the Niagara limestone at Niagara, and in the lower gorge of the Genesee. The next epoch is the Niagara. It it is one of the great limestone-making intervals. This is equivalent to saying that the waters of the region where Niagara rock is now found were not beclouded with land waste, and were of some depth. It appears but slightly along the Appalachians, is about two hundred feet thick in western New York, is found thence to Iowa, and occurs in the Black Hills of Dakota. It is one of the most extensive formations of the State of Iowa. Many quarries are opened in Niagara limestone in Chicago, and the channels of the Illinois and Mississippi Rivers and of the Drainage Canal are excavated in this formation.

The rocks of the Salina epoch consist of red and green marly shales, and associated drab limestones, which afford hydraulic cement. Hence these upper beds are sometimes called the Waterlime group. The distribution of the Salina is similar to that of the Niagara and Clinton, but it is not known in the far West. The rocks represent a period of shallow and often quiet waters, in which, by evaporation, much rock salt was formed. The Waterlime formation is so called from the hydraulic limestone afforded by it, and extensively quarried at Rondout, N. Y. The Tentaculite limestone has been so named from its common fossil. It may better be called the Manlius limestone, from a town in central New York.

In New York the Medina, Clinton, Niagara, and Salina rocks thin and nearly or quite run out to the eastward, though most of them reappear going south into Pennsylvania. None of the Upper Silurian epochs are well represented in the Rocky Mountain region, so far as present knowledge goes. The continental evolution which went on so steadily in the East throughout the Paleozoic era was well-nigh finished in respect to extent of land before the western half of the continent fairly entered upon its growth.

The variety of geographic conditions represented by Silurian rocks should be observed. Thus we have shore formations in the Medina, shallow waters in much of the Clinton and Salina, and limestone making in the Niagara, Rondout, and Manlius epochs.

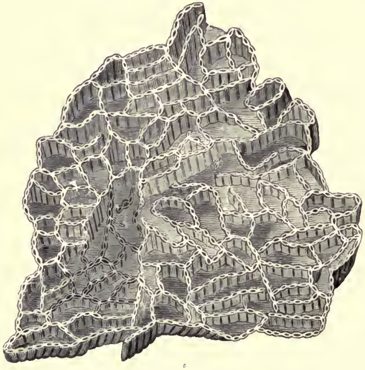


FIG. 178.—Halysites (Chain coral).

**327. Life of the Upper Silurian period.**—Organic development continued along the lines followed in the two preceding periods. There were no abrupt or striking introductions or extinctions. But the law of organic unfolding was illustrated by the decline or disappearance of some species and genera and the quiet entrance of others on the scene.

Undoubted land plants are found fossil in a few cases in Upper Silurian rocks. Their rarity does not prove that land vegetation may not have been common, for we must remember how subject to decay land forms are. The Graptolites decline from their culmination in the previous period and become nearly or quite extinct. The corals, however, flourish in great profusion, forming true coral reefs in the Niagara epoch. The Echinoderms are represented not only by a multitude of Crinoids, but by the forms so abundant in modern seas, the starfishes and sea urchins. Brachiopods continue in great force, and there are some noteworthy introductions of new sorts, such as the Spirifer, the Atrypa, and the Pentamerus.

Fig. 179.—Spirifer audaculus, showing interior structure. (This species is Devonian.)

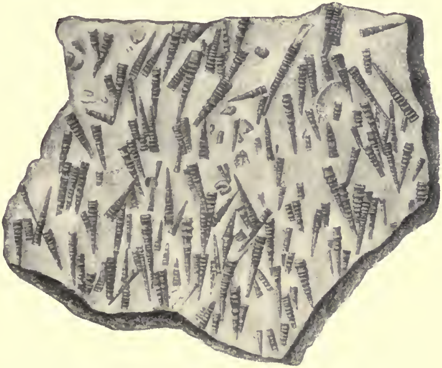


Fig. 180.—Block of limestone, showing numerous Tentaculites.

The Spirifers are a noteworthy genus which comes in during the Clinton epoch, and increases in the number of species and of individuals during subsequent epochs and periods, but becomes nearly extinct at the close of the Paleozoic era. They carry within two calcareous spiral coils, which are often well displayed in weathered specimens or artificial sections (Fig. 179). The form of the shell is

Fig. 181.—Block of Niagara shale, showing three specimens of Calymene Blumenbachii. At the top is the caudal shield of Homalonotus.

various, but especially triangular, with a long straight hinge, and sometimes a broad, smooth, curved hinge area. Several species from the different epochs will be shown in the figures as we proceed. The Atrypa is another genus which continues through many epochs and has a number of species. The shell is nearly circular, and often an inch in diameter. Commonly one valve is much more plump than the other, and sometimes in the later epochs the surface is covered with spines.

Pentamerus—so named from a fivefold division of its interior—is a plump shell, one to two inches in diameter, one of whose valves has a prominent rounded beak. Certain species of it occur in the Clinton rocks. It must not be thought that these are all the important Brachiopods of these ancient seas. Many others are of great numbers and interest, but in an elementary work only a few of the most characteristic forms can be noticed. A sense of the reality of ancient organisms, and of the progress of life throughout the earth's history, is what the student should win from the present study.

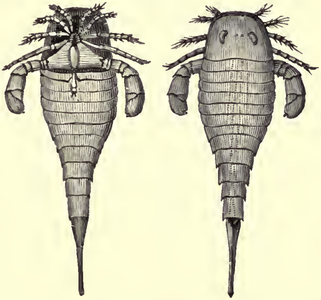


Fig. 182.—Eurypterus restored, ventral and dorsal views.

The Mollusks still yield the palm to the Brachiopods, though all the classes are represented. Pleurotomaria and Murchisonia continue from the Lower Silurian, and the Avicula, a Lamellibranch with a winglike extension, is not uncommon. A new Pteropod is characteristic of the Tentaculite or Manlius limestone, a small, slender shell with ribs, shown in Fig. 180, and often covering the surfaces of the beds. The Trilobites are still abundant, though not so conspicuous an element in the fauna as in Lower Silurian times. In the Waterlime or Rondout beds are many remains of Eurypterus, shown in Fig. 182. It often grew to a foot in length. Associated with these forms, a scorpion was found some years ago, near Waterville, N. Y. It has the great interest of being the first air-breathing creature yet discovered in American rocks, though two or three of equal or greater age have been found in Europe. A few fish remains are found, but they do not become abundant until the Devonian times. An account of the early fishes is reserved for the chapter on that period.

A few plant remains are reported, which are important as representing beginnings. Certain markings or networks of stemlike forms are common in Medina rocks, and were formerly described as plants.

FIG. 183.—A Silurian scorpion (from Scotland).

328. **Economic products of the Upper Silurian period.**—As in most rock systems, building stones are furnished by some of the series. Thus Medina sandstones are considerably used, especially for paving purposes. Niagara rocks are locally employed for building and for making quicklime. The iron-ore beds of the Clinton epoch have been considerably worked in New York and other States. The ore is a red hematite, oölitic, and often containing fossils. The most important product of American Upper Silurian rocks is common salt. It must not be thought that salt beds are peculiar to any one period. They may be accumulated at any time when shallow basins of sea water become more or less isolated from the main ocean. If, in addition, the land keeps a stable position relative to sea level, and little land waste is brought in, evaporation may go on in these natural pans until beds many

feet thick are formed. An influx of mud, as during a flood or storm season, may leave its record as a layer of shale between two beds of salt. Hence it is that salt beds of Cretaceous age are found in Louisiana, brines of lower Carboniferous age in Ohio and Michigan, massive rock salt of Triassic age in England, and especially in Germany, where the beds are many hundred feet thick.

FIG. 184.—Rock salt of Salina age, western New York. Two-foot cube and smaller mass with natural fracture. Museum of Colgate University.

Such, then, were the conditions that prevailed in central and western New York, in parts of Ohio and Ontario, during much of the Salina epoch. Throughout the present century, and even earlier by Indians, salt springs were known in the region of Syracuse, N. Y. For many years the brines obtained by borings have been evaporated in solar vats and by boiling. About twenty years ago a chance boring for oil in western New York was the means of finding the actual salt beds of the formation. They are sometimes 80 feet thick and occur along the Genesee River and eastward to the center of the State. As the Salina shales dip southward beneath the younger rocks, the salt is found at varying depths, from 800 feet on the north side of the belt to 3,000 feet on the south. Beds of similar age are found near Cleveland, Ohio, and Goderich in Ontario, showing that a large area was affected by salt-making conditions. Gypsum, both crystalline and massive, is found in rocks of the same epoch. It is in workable quantities and is extensively ground and sold as a fertilizer.

## CHAPTER XX

### PALEOZOIC ERA

### Devonian Period

329. **General statement.**—The period receives its name from the county of Devon in the south of England, where its formations are typically seen. The designation is universally adopted. The Devonian period in North America succeeds the Silurian in a quiet manner, without mountainous upturnings, and it is characterized in the East by a great series of shales and sandstones. It marks a considerable growth of land, and thus paves the way for the more nearly continental conditions of Carboniferous times. A great increase of land plants, forming forests, and the widespread development of the fishes, are the important biological changes.

330. **Epochs of the Devonian.**—We give them as follows:

| | |
|---|---|
| Devonian Period....... | 5. Chemung Epoch. |
| | 4. Hamilton Epoch. |
| | 3. Corniferous (Onondaga) Epoch. |
| | 2. Oriskany Epoch. |
| | 1. Helderberg Epoch. |

In this classification no account is taken of certain local formations occurring chiefly in the State of New York. Some of them will be mentioned in the appropriate connection. The earliest epoch of the Devonian is the Helderberg,* whose rocks form a deposit 300 feet thick in east-

* The Helderberg is here transferred from the top of the Silurian to the base of the Devonian series, following J. M. Clarke and other authorities.

ern New York and extend far south. They are unimportant in the West, but are found in the Connecticut and St. Lawrence Valleys, and in northern Maine and Nova Scotia, showing the wide sweep of Helderberg waters in the East. They are limestones with abundant fossils. This means that the northeast shore of the Interior Sea was considerably submerged and that animal life flourished in clear and quiet waters. Above the Helderberg rocks lies the Oriskany sandstone, so named from the village of Oriskany Falls, southwest of Utica, N. Y. It is there but 12 feet thick, and passes abruptly to the Lower Helderberg limestone below and the Corniferous limestone above. It consists of coarse quartz sand, and thus shows two abrupt changes of deposit, and, like the Medina, its outcrop represents the east and west shore line of the Interior Sea in New York at the beginning of the Devonian time. Southward along the Appalachians it is often of greater thickness, as in Maryland and Virginia. It disappears in western New York, but occurs in Ontario and southern Illinois.

331. The Corniferous * epoch is so named because of the nodules and layers of flint or hornstone which its rocks contain. They were formed by the solution and concentration of the siliceous matter of protozoans and sponges, as is proved by the finding of such structures when the flints are studied under the microscope. The limestone is full of fossils, and the organisms have produced small quantities of the mineral oil which is sometimes found in the formation. The Corniferous rocks extend westward from New York, and are well developed in several States of the central West from Ohio to Iowa and southward.

332. The Hamilton rocks are so named from typical exposures on the lands of Colgate University and elsewhere in the town of Hamilton, N. Y. They consist of a great

* Onondaga (Clarke and Schuchert) is a better designation, referring to extensive displays of these rocks in Onondaga County, N. Y.

series of shales and shaly sandstones, 1,200 feet or more in thickness, and extending east and west in a belt about 20 miles wide. They are sandy in eastern New York, but more calcareous going westward, where the water was deeper and received less land waste. About 100 feet of black mud rock, called the Marcellus shale, lies at the base as a kind of bed of passage from the Corniferous limestones to the sandy deposits of the typical Hamilton. This epoch is extensively represented in other States and parts of the continent. Its beds attain a maximum thickness of nearly a mile in Pennsylvania, and are known westward to Wisconsin, and in all the States which border the Ohio River.

333. The Chemung rocks are a great series (sometimes several thousand feet in thickness) of shales and sandstones. In central and western New York the lower and older parts of the Chemung are locally designated as Portage, Ithaca, and Oneonta. The typical Chemung lies geologically higher and forms a surface belt along the southern border of the State. Eastward a great column of sandstones—mostly barren of fossils—forms the Catskill Mountains, but is believed to be the thick shore formation, identical in time with the finer and more fossiliferous beds farther west. Chemung rocks have even greater thickness in parts of Pennsylvania. The "black shale" is a thin, widespread equivalent of the Chemung series, made in the bottom of the Interior Sea south and west. Thus in almost every instance we have found thick and often coarse fragmental beds forming in the East, and thin, generally calcareous beds in the Mississippi Valley region.

The coarse materials of the East were brought by streams, which then pursued a westward direction from the unknown extent of land that then lay along the Appalachian belt, and perhaps considerably eastward over the present domain of the Atlantic. Land waste some miles in thickness laid on a sinking sea floor from New York to

Alabama requires some adequate body of land for its derivation. This could only have lain to the eastward.

The students must not forget the islands which occupied the central parts of the Interior Sea in the region of Cincinnati and southward. About these as well as along the older shores, the Silurian and Devonian formations were accumulating, so that as we come to the close of Devonian times and the opening of the Carboniferous, we find shallow waters and nearly inclosed marine gulfs where, in pre-Silurian times, there had been a sea open far to the west.

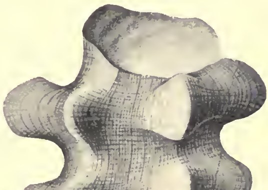


Fig. 185.—Hydnoceras Avoca, a Devonian sponge, southern New York.—After Hall and Clarke.

Considerable Devonian formations are found in the western region of the United States. The chief are in the Wasatch Mountains, in the Grand Cañon district, in Nevada and California. Another belt of Devonian rocks, correlated with the Hamilton series, occurs in the valley of the Mackenzie River, and southward to Manitoba. Others still occur in the eastern border region, as defined by Dana—that is, the Gulf of St. Lawrence, and in Nova Scotia and New Brunswick.

334. **Life in the Devonian period.** — No mention has hitherto been made of the Sponges, some specimens of which, however, are found even in the Cambrian, and they are not uncommon forms in the Trenton, Niagara, and

Helderberg limestones. They occur in the Corniferous limestones also, and their siliceous spicules are found in the nodules of flint. Various species appear in the Hamil-

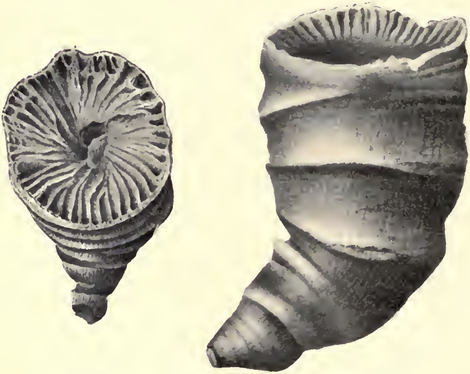


FIG. 186.—Coral, Zaphrentis Roemeri, Helderberg epoch.

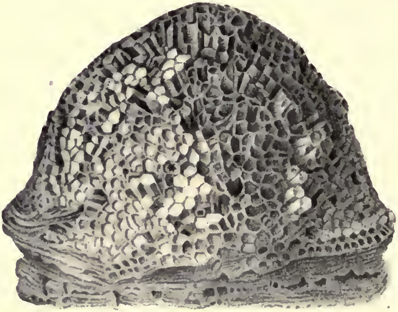


FIG. 187.—Coral, Favosites conicus, Helderberg epoch.

ton and Chemung epochs. The Chain corals were never abundant and are not known in the Devonian. Thus we record another extinction of an organic group, as we shall so often have occasion to do. The Cup and Honeycomb types remain in great force, as seen in the Helderberg, Corniferous, and parts of the Hamilton series. A noted reef of these ancient Devonian corals gives origin to the falls of the Ohio River near Louisville.

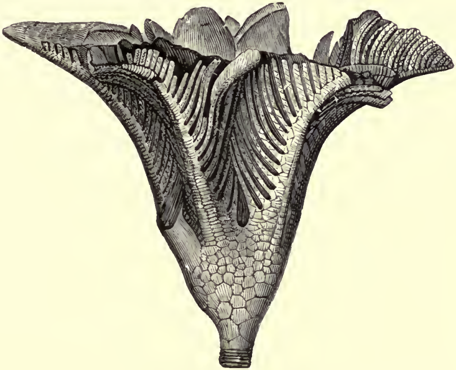


FIG. 188.—A Devonian Crinoid.

335. The Cystids, or more primitive Crinoids, have disappeared and the Blastoids begin to come in. The true Crinoids with branching arms continue to be numerous, except in the later Devonian. The Chemung seas of the East were too muddy to favor their growth. The student must not think that the absence of a group from the rocks of one region means that they did not flourish somewhere during the same time. They maintained their course in more favoring seas, and often migrated back to the same region in a later epoch or period, and deposited their remains in overlying rocks. The starfishes or Asteroid group of Echinoderms appear to have begun their existence in Lower Silurian seas, and have thus far gained no great

numbers, but highly elaborated examples are not uncommon in the Hamilton rocks.

336. The Brachiopods keep their large place as a Paleozoic type. Some genera come up from the Silurian, but a

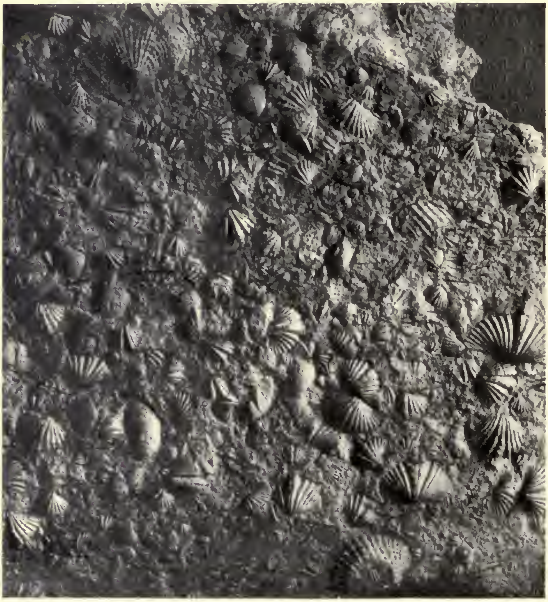


Fig. 189.—Atrypa, Spirifer, and other Hamilton fossils in association upon a single slab.

great number of genera and most species are new. In general they show a greater degree of ornamentation than the pre-Devonian kinds, or more elegance and variety of form. Frequently they are equipped along the hinge line, or over their entire surface, with spines. The Lingula and Discina continue to be common forms. These are known as inarticulate Brachiopods—that is, without bony projections or processes for hinging the two valves of the shell together. Of the hinged or articulate Brachiopods,

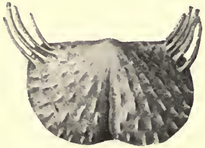


Fig. 190.—Productella Boydi, Chemung.

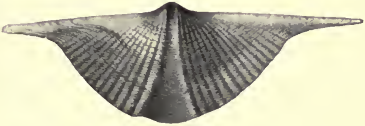


Fig. 191.—Spirifer mucronatus.

the Orthis, Atrypa, and Spirifer come from earlier times, while Productella appears for the first time. *Pentamerus galeatus* is an important species of the Helderberg limestone. Two or three species of Spirifer will be especially named. Thus, a large, coarse-ribbed species, *Spirifer arenosus*, is common in the Oriskany sandstone. A thin form with long hinge and pointed extremities is extremely characteristic of the Hamilton series—viz., *Spirifer mucronatus.* It has a fanciful resemblance to a butterfly, a feature which is often noticed by those unacquainted with geology. *Spi-*

Fig. 192.—Orthis Vanuxemi. Ventral and profile views.

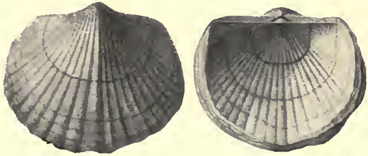


Fig. 193. — Tropidoleptus carinatus. A Hamilton Brachiopod. Ventral and dorsal views.

*rifer medialis* and *Spirifer granulifera* are other Hamilton species. *Spirifer disjunctus* belongs to the Chemung, but has a wide range, being found in Europe as well as in America. *Atrypa reticularis* is common in the Hamilton, as in several previous epochs, and *Atrypa aspera*, a spinose form, shows well the increasing elaboration of the Devonian shells. *Rensselaeria ovoides*, egg-shaped, as the specific name indicates, is a large characteristic form of the Oriskany epoch.

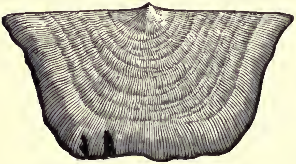
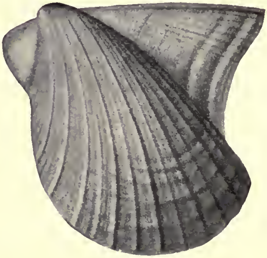
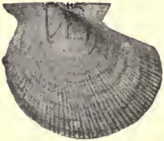


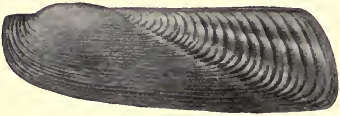
FIG. 194.—Leptæna rhomboidalis.



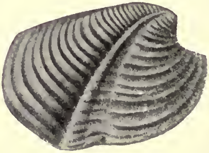
Pterinea flabella.



Aviculopecten fasciculatus.



Orthonota undulata.



Grammysia bisulcata.

FIG. 195.—Characteristic Middle Devonian (Hamilton) Lamellibranchs.

337. The Mollusks are growing in abundance both of species and individuals, thus looking toward the more

modern times when they should take precedence of the Brachiopods. Especially do the Lamellibranchs thrive in the sandy waters of the Hamilton and Chemung epochs. Among the common bivalves of this class in the Hamilton

Fig. 196.—Goniatites Patersoni, western New York.

strata we find: *Pterinea flabella*, about two inches across, with wings and the surface covered with coarse ribs; *Orthonota undulata*, a narrow form with a straight hinge, and various species of Grammysia. Nine hundred species of Devonian Lamellibranchs have been described. The straight and curved shells of the Cephalopods are found as in previous periods, though fewer and smaller, but the coiled Cephalopods make a new advance in the Goniatite of the Lower Hamilton. The student will recall that the cross partitions of the Orthoceras are plain, or simply curved, like those of the existing Nautilus. But in the Goniatite they are crimped, or strongly curved back and forth, as seen in Fig. 196. This is the ancestor of the Ammonite type, which comes to its height in Mesozoic times. Thus we have another illustration of the small beginnings and gradual unfolding of the great types of life, both on land and in the sea.

338. Trilobites are still numerous, but neither they nor the Cephalopods longer rule the seas; Homalonotus is a long and large form, sometimes 8 to 10 inches in length, found in earlier periods, but living abundantly in the Hamilton epoch. Here are also found great numbers of the Trilobite Phacops rana, illustrated in Fig. 199. But few Trilobites are found in the upper Devonian rocks. The Crustacea are also represented by large Eurypterids and by creatures somewhat like the lobsters of to-day. Leperditia, a small crustacean with an elliptical shell or case, is common in some beds of Helderberg limestone. Insects, like cockroaches and dragon flies, become common, keeping pace, according to a general law, with the progress of land plants.

Fig. 197.—Homalonotus Dekayi, Onondaga County, N. Y.

Fig. 198.—Eye of Phacops rana, showing lenses.

Fig. 199.—Phacops rana, a common Trilobite in Hamilton rocks, Genesee County, N. Y.

339. The great advance in the Devonian period is in the number and variety of its fishes. They are not the

Teleosts, or fishes with bony skeletons of to-day, but are strange and primitive forms. Instead of being covered by

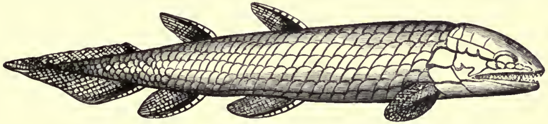


FIG. 200.—Osteolepis.

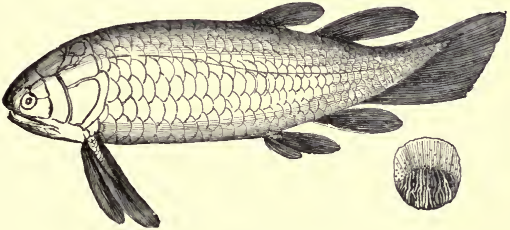


FIG. 201.—Holoptychius.

flexible scales familiar to us, they were often incased in a strong armor of large bony plates, or covered by an integument of smooth, hard scales, often of rhomboidal shape.

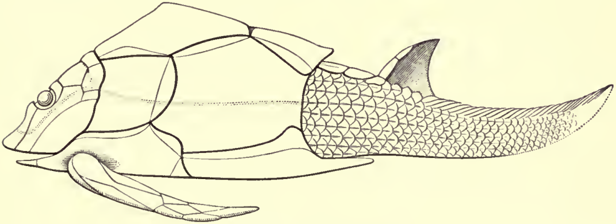


FIG. 202.—Ptericthys restored.

On account of these characters the former are called Placoderms (plate skin), and the latter Ganoids (luster). The

Selachians were fishes with skeletons of cartilage, like modern sharks. Some ancient fishes had sharp teeth, others a pavement of hard plates for crushing. A frequent character also was the unsymmetrical tail, the spine being

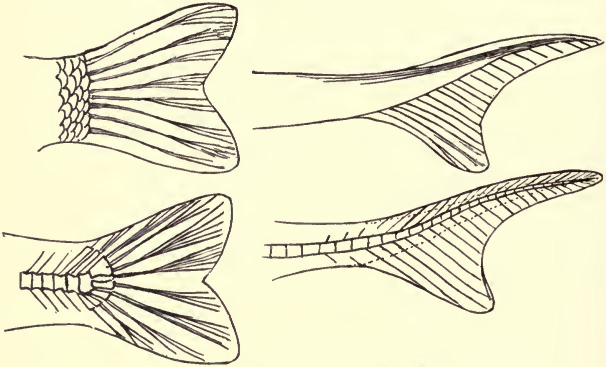


FIG. 203.—Vertebrated and non-vertebrated fish tails.

prolonged through one lobe of the tail fin. Several of these features are shown in Fig. 203. Some Devonian fishes were of great size, notably Dinichthys (which simply means terrible fish), of the Ohio Devonian, said to have a length of 18 or 20 feet. In some Devonian beds of Scotland, Hugh Miller and others have found the greatest profusion of fossil fishes, as though shoals of them had been suddenly killed by some catastrophe.

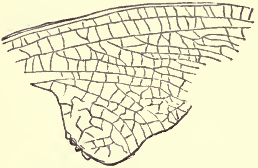


FIG. 204.—Wing of a Devonian insect.

340. For the first time in the history of the earth, land plants now become abundant. There were both herbaceous plants and trees, mostly of ferns, lycopods, and horsetails, belonging to the flowerless plants. These earliest forests

of the globe were inhabited also by insects of lower types, but some were of large size. The higher flowering plants were still absent, and were so to remain for a very long period. Nearly inclosed bays and lakes of brackish or fresh water were perhaps common, and such was the case in an important way in Scotland during the accumulation in such basins of thousands of feet of the Old Red Sandstone, which is believed to correspond in time with the marine shales and limestones of Devon and Cornwall, the typical Devonian of Great Britain. Geographic conditions both of land and water were becoming varied, and these were accompanied by correspondingly varied types of animal and plant life.

FIG. 205.—Cephalaspis from the Old Red Sandstone. See section 340.

341. **The North American continent at the close of the Devonian period.**—It must be remembered that marine rocks can not form land during their deposition, but only after their upheaval. Such slow uprising in far-distant periods it is impossible definitely to trace. The limits of the next younger system of rocks do not coincide with the sea borders of the following period, because we can not know how much of the later sediments has been removed by erosion. Hence all maps reconstructing a continent at a given time involve more or less of conjecture. But their general truthfulness makes them instructive and useful. Dana gives such a map representing the progress of the American continent at the time to which we have now come. The Atlantic shore line is somewhat eastward from

its present position, from New England southward. The Appalachian belt of land does not extend beyond central Georgia and northeastern Alabama. Its northwest shore runs from northeastern Pennsylvania through the Virginias and Eastern Tennessee. The border of the Interior Sea passed along the southern border of New York and Lake Erie, and then ran around most of the southern peninsula of Michigan, south of which are the lands of the Cincinnati Anticline which now form a peninsula joining to the mainland on the northwest in northern Indiana and Illinois. Thence the western shore line extends northwest through northern Iowa, western Minnesota, and far away through Canada. A large island lies in Missouri, south of the Missouri River. Of the details of the surface and of the river systems of the time we know nothing.

Fig. 206.—Devonian ferns from New Brunswick.

342. **Economic products of the Devonian period.**—Some beds of the Corniferous limestone are used for building, and locally also the Hamilton and Portage sandstones. The so-called North River flags are quarried from Hamilton beds in eastern New York. Slabs of great size are sometimes obtained, owing to the infrequency of joint planes. The same is true of Chemung rocks in some parts of southern New York. The most important prod-

uct of American Devonian rocks is the petroleum of western Pennsylvania, southwestern New York, eastern Ohio, and West Virginia. It is stored by Nature in what are called the "oil sands," which are beds of porous sandstones

FIG. 207.—Devonian forest restored.

of late Devonian age. The productive sandy layers in a given place may be one, two, or three in number, at varying intervals in going down. A "sand" may be productive at one place and barren at another. The oil is supposed to have been produced by the decomposition or slow distillation of organic matter in still lower beds. In the earlier days of the oil industry spouting wells were common, owing to the pent-up gases held with it in the rocks. Now, moderately flowing or pumping wells are the rule. It is a common practice to "shoot" new or waning wells—that is, to explode at their bottom a heavy charge of nitroglycerin, by which the rock is shattered, channels opened, and the flow increased. The oil is piped to local reservoirs, much of it is worked into various products at neighboring refineries, and much is carried by great pipe lines to distant cities.

Many limestones and shales contain a little oil, which may gather on the surface of pools or streams, and thus by deceptive indications lead to unprofitable investments. Even in the oil region the geologist can determine at what depth a given oil sand will be met in boring, but he can not say whether or not it will prove productive. Crude oils vary much in composition, specific gravity, and color.

# CHAPTER XXI

## PALEOZOIC ERA

### Carboniferous Period

343. The names of the other Paleozoic periods have had some connection with a locality. This period is so named from the abundant carbon stored in the rocks in the form of coal. As the conditions for making rock salt may recur a number of times, so this is not the only period in the earth's history when coal was formed; but here we find the earliest deposit which has economic value, and at the same time it is by far the most abundant, taking the lands as a whole. Coal being the most important mineral product of the earth, with the exception of iron, careful study has been devoted to most areas where it occurs, or is supposed to occur. This is done both by private and by government enterprise. An incidental result is the abundant knowledge of a purely scientific nature which we have of the Carboniferous times. When we say this, however, we must remember two things: first, that the truth of science has the highest educational worth in itself; and, second, we never know how soon such truth will have value in the common affairs of men.

344. **Subdivisions of the Carboniferous period.**—Three subordinate periods are distinguished—namely, the Early, Middle, and Late Carboniferous. The first of these is more commonly called the Lower, or Sub-Carboniferous—a designation which is used more suitably of the rocks themselves

than of their time of deposit. The second is the Carboniferous proper, or period of the Coal Measures. By coal measures we mean the rock strata with which the coal beds are associated. The coal itself, as we shall see, is small in bulk and area as compared with the rocks which contain it. The Late Carboniferous is called the Permian, from the government of Perm in Russia. It is often considered as a distinct period following the Carboniferous, but, as its formations are less full in North America than across the seas, it is better in this elementary study to retain it in a subordinate position. We shall take up the main divisions of the Carboniferous in their order. We must first observe that New York has now become mainly a land surface, and its rocks no longer furnish a scale of comparison. We shall distinguish four of the more important regions of deposition:

1. The Interior Sea of the East. This has now become a "double-headed bay," reaching to northeastern Pennsylvania on the one hand, and over southern Michigan on the other. A great peninsula stretches from southern Wisconsin southeast over the region of the Cincinnati Anticline, and thus divides these secluded waters from the region of the Mississippi Valley.

2. We therefore set the central Mississippi country by itself, and find in it a typical series of rocks.

3. The Eastern Border, which, as emphasized by Dana, has been a place of accumulation throughout earlier Paleozoic times.

4. The region of the Rocky Mountains and westward.

345. **Early Carboniferous of the several regions.**—We have seen that in the later Devonian epochs the Interior Sea in New York and Pennsylvania received a vast deposit of coarse rocks, while west and south the beds were thin and fine. Denudation seems to have been active around the head of the great gulf. There perhaps were the highest mountains, the largest lands, and the most powerful rivers.

The same conditions held on there in the Early Carboniferous times. Two formations were made in Pennsylvania. The Pocono sandstones and conglomerates form much of the plateau surface, especially in northern Pennsylvania. They are followed and overlain by the softer Mauch Chunk shale. These subdivisions correspond in importance with those of the epochs already studied. Their formations pass into limestone, as we go southwest to Virginia, Tennessee, and Alabama.

The corresponding rocks of Ohio are called the Waverley group, and in Michigan the Marshall group.

In the Mississippi region we have another succession of deposits. They are all limestones and hold the greatest profusion of marine fossils. They cover large areas in Indiana, Illinois, Iowa, and Missouri. The names Kinderhook, Osage, St. Louis, and Chester are applied to the several groups or series of rocks and to the epochs during which they were formed. Sandstones, shales, and limestones of Early Carboniferous age are distinguished in Nova Scotia and New Brunswick. As there is no coal in the Carboniferous system of the far western region, its subdivisions are not so well known, and indeed may not in any great degree correspond with those of the East.

346. **Coal measures.**—We take first those of the Eastern interior. Here Pennsylvania becomes the typical State, both because the formations occur on a grand scale and because the geological surveys of the State have during many years been carried to a high degree of perfection. The first geological survey was executed by the brothers H. D. and W. B. Rogers, and the second survey, under Lesley, has issued more than 100 volumes, covering all counties of the State and exhibiting the coal formations to the fullest degree.

A great series of coarse rocks, known as the Pottsville Conglomerate, forms the foundation of the coal measures in the East. Then succeed shales, sandstones, limestones, and beds of coal, alternating with each other in almost any order. Taking a given bed or "seam" of coal, it may be a few inches or several feet, or rarely 40 to 50 feet thick, and is commonly found in the following associations: Below is a clay, often known as the fire clay, which frequently contains stumps and roots of the ancient trees. Above lies the coal, which is a true bed, though often called a seam, or incorrectly a vein. Like other sedimentary rocks, it will be nearly horizontal unless disturbed, in which case it may stand at any angle. The coal may be solid throughout, or may have interbedded thin layers of shale or "bone." These may become so numerous as to unfit the bed for working. Above the coal, forming the roof in mining, is another shale, often packed with ferns, leaves, stems, or other remains of plants. They mark the time when fresh earthy sediments invaded the coal-making swamps and buried the last growth of vegetation. Above this shale may come a sandstone, a mass of shale, or a limestone, or a succession of these, which may be thin or thick, and may have been laid down in a fresh-water lake, a brackish-water bay, or comparatively open sea, depending upon the amount of subsidence and the surrounding geographic conditions. What these conditions were, and what the succession of geographic changes was, we are now prepared to understand.

By sedimentation, or by the general uplift of the growing continent, a sea area becomes a broad marsh or a region of swamps and lowlands. The climate is warm and moist, and the forest develops in great luxuriance with the smaller ferns and other undergrowths. In these moist areas the vegetation is preserved and accumulates like the peat of present times. After a greater or less period, for the making of a thick or thin carbonaceous layer, subsidence ensues, the waters come in and the vegetable layer is covered by mud, perhaps of a delta, fine or coarse, making shale or sandstone according to the topography and rocks of adjacent lands, or a greater sinking carries the region somewhat offshore, the waters become clear, marine life flourishes, and limestones are made. After a time fresh elevations, or continued deposit, bring the bottoms near to the surface again, and the coal swamps are renewed. That the student may better appreciate the remarkable way in which rocks and coals are thus interleaved, the following table is given nearly as reproduced by Dana from the Pennsylvania Reports:

*Monongahela River Series*

| | Feet. |
|---|---|
| Shale and sandstone | 70–82 |
| Waynesburg main coal bed | 6 |
| Sandstone and shale, 60; limestone, 5; sandstone, 20; fire clay, 3 | 88 |
| Uniontown coal bed | 1–3 |
| Sandstone and shale, 60; limestone and shale, 18; sandy shale, 40; limestone and shale, 55 | 173 |
| Sewickley coal bed | 1–6 |
| Sandstone and shale, 25; limestone, 18; sandstone, 10 | 53 |
| Redstone coal bed | 1–6 |
| Shale, sandstone, and limestone | 50–62 |
| Pittsburg coal bed | 5–12 |
| Fire clay | 3 |
| | 494 |

It will be seen that the greatest thickness of the above series is 494 feet, and that there are 5 coal beds, in all from 14 to 33 feet. Shales and clays are noted as occurring 10 times, sandstones 7 times, and limestones 5 times. Probably many minor alternations are not recorded in the table. Nothing could better illustrate the freedom of all sedimentary series of rocks from arbitrary rules. Each case must be studied by itself, and the wonder is not that so few but that so many general laws can be ascertained after long courses of patient investigation.

In order to explain the present arrangement of the coal beds of Pennsylvania, we must for a moment anticipate the mountain-making which closed the Paleozoic era. The rocks and coal beds of eastern Pennsylvania were thereby much upturned and folded, and the anthracite fields, like that of Scranton and Wilkesbarre, lie in great canoe-shaped

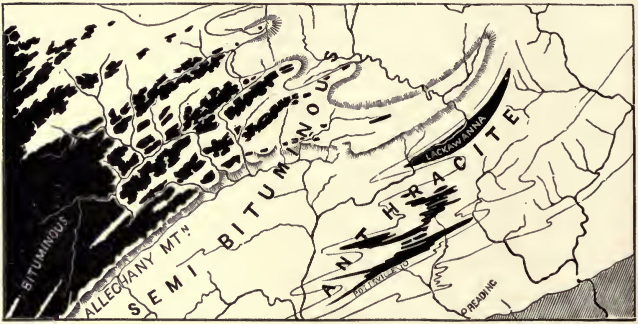



Fig. 208.—Map of Pennsylvania coal regions.—After Lesley.

synclinal valleys, while immense areas of rock and coal have been denuded from the intervening anticlinal arches. The anthracite of the east is of the same age with the soft coals of western Pennsylvania, only the former is metamorphosed by mountain-making pressures. No doubt the two coal areas were once continuous, and the coal fields of Broad Top surviving between the two are an impressive proof of this. The same great coal field extends in an important way into eastern Ohio and southwest through West Virginia, eastern Kentucky, and Tennessee into Alabama.

The coal measures of the central Mississippi areas also contain two great coal fields, which may have been one until their continuity was destroyed by erosion. The eastern area lies in Indiana, southern Illinois, and western Kentucky; the western is larger, extending from south-

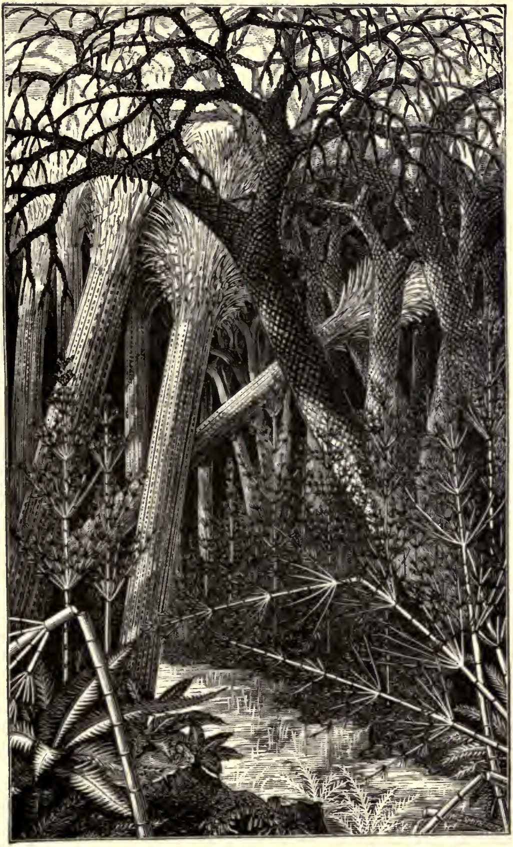


Fig. 209.—A forest of the Coal period.

western Iowa over parts of Missouri, Kansas, Arkansas, and Indian Territory, into Texas. There is, besides, a region of coal measures in the southern peninsula of Michigan covering 7,000 square miles. They were formed, as it appears, in a closed basin, and with the lower rocks help to form a succession of strata like a series of gigantic saucers of diminishing size.

On the eastern border small coal areas are found in New England, especially in Rhode Island. The coal is a hard anthracite, sometimes almost like graphite, but the vegetation is typically Carboniferous. The great coal deposits of the Eastern Border are in Nova Scotia. Seventy-six dirt beds are recorded, of which 15 contain deposits of coal. The total area of Carboniferous coal measures in North America is more than 200,000 square miles.

347. **Carboniferous formations of the Rocky Mountains and Pacific slope.**—These are Carboniferous only in name, and are so called because belonging to the period of coal accumulations in the East. The extensive soft coals of Colorado, Wyoming, Washington, and other States are of later age. Carboniferous strata outcrop in Colorado at the eastern foot of the Front Range. In the Grand Cañon region they are important, and are called the Aubrey sandstone and limestone. Thirteen thousand feet of rocks of this period occur in the Wasatch Mountains. Strata of this time are also found in the Great Basin and in the Sierra Nevada, and are reported by the Canadian geologists from a number of arctic localities.

348. **Further observations on the coal measures.**—Here we note first the unquestionable vegetable origin of the coal. It is shown by the order of association of the coal with its contiguous beds, soil and roots below, with trunks and branches above. It is also proved by the preservation of vegetable structure, such as cells, within the coal itself, and accessible to microscopic study. If further confirmation were needed, we should find it in the coal series, rang-

ing from freshly deposited vegetation through all grades of peat, lignite, and bituminous coal, to anthracite and graphite. It is time also for the student further to ponder upon the vast period of time needful for the operations which we have now described. We have seen that there were 76 successive swamps with intervening rock forma-

Fig. 210.—Vegetable structure in coal (as seen under the microscope).

tion in Nova Scotia. More than 100 of these alternations are reported from South Wales. Every foot in thickness of coal has required several feet of fresh vegetable matter, and the oscillations, of which there were so many, no doubt went on as slowly as such changes now take place on the New Jersey or Scandinavian shore.

349. **Late Carboniferous or Permian rocks.**—Only a general reference is needful here. About 1,000 feet of the upper "barren measures" of Pennsylvania and West Virginia are of this age. With these are classed certain beds lying over the coal measures from Nebraska to Texas, and

at the top of the Carboniferous system in the Grand Cañon region and in Nova Scotia. As already suggested, the Permian formations assume great importance across the seas.

Fig. 211.—Group of Carboniferous ferns.

## Life in the Carboniferous Period

350. **Plants.**—We have seen that land plants begin to appear probably as early as Lower Silurian times, and that they were in considerable force, even making forests, in

the Devonian period. We now, however, see them in great prominence. They are a large part of the living world, and also form the culmination of Paleozoic veg-

Fig. 212.—Foliage of coal plants.

Fig. 213.—Calamites, resembling modern horsetails.

etation. Some of the chief kinds of Carboniferous plants form but a small part of the world's flora in all later periods.

About 2,000 species of plants are known from Carboniferous rocks, or about one fourth of all reported fossil plants. And this great display of vegetation took place some millions of years ago. Several hundreds of species of fern are found, many of them preserved with the perfection and beauty of a herbarium of modern ferns. Some were tree ferns, like some still found in tropical forests.

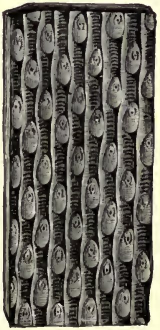


Fig. 214.—Sigillaria.

To the class of Lycopods belong two very important sorts of Carboniferous trees, which form a large part of the material for the beds of coal. One is

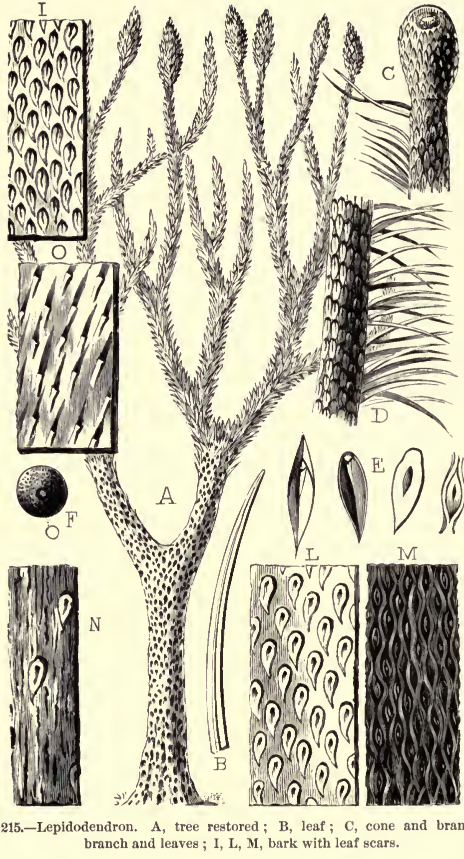



**Fig. 215.**—Lepidodendron. A, tree restored; B, leaf; C, cone and branch; D, branch and leaves; I, L, M, bark with leaf scars.

the Lepidodendron, or scale tree, so called from the diamond-shaped leaf scars arranged in spiral order and covering the surfaces of trunk and limbs (Fig. 215). These trunks were sometimes from 2 to 4 feet in diameter, and the trees attained a height of more than 50 feet.

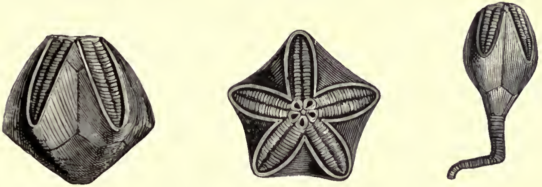


Fig. 216.—Carboniferous Blastoids.

The Sigillaria, or seal trees, had trunks marked by fluted columns, and a vertical row of leaf scars resembling a seal is found on each column. The trunks were mostly a cellular mass, but they possessed pith and medullary rays, and thus combined the characters of modern endogenous and exoge-

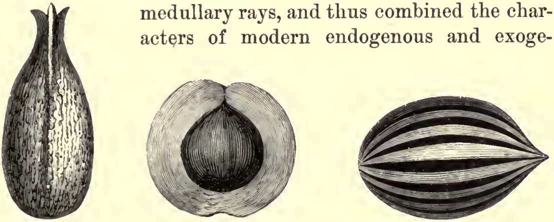


Fig. 217.—Carboniferous fruits.

nous plants. This is an important fact, for it shows that in the plant as in the animal world the ancestral forms often combine features of structure which are found in separate and special types to-day. This helps us to think of all living forms, from the dawn of life until now, as forming a family or evolutionary tree.

Fig. 218.—Fusulina, two views, enlarged.

Another class which has its greatest examples in the

Carboniferous period is the Equiseta, or horsetails (Fig. 213). These were jointed plants like the common diminutive horsetails now growing in moist places, or the familiar scouring rush. The stems were fluted, and bore a whorl of leaves at

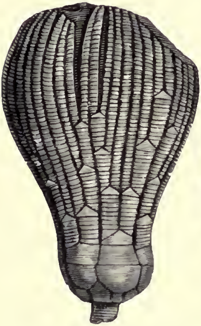


Fig. 219.—A Carboniferous Crinoid.

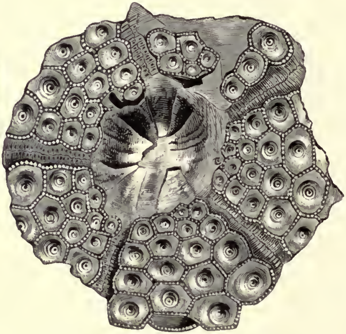


Fig. 220.—A Carboniferous sea urchin.

each joint. They attained the size of trees, growing to a height of 20 to 40 feet. All the forms thus far named belong to flowerless plants. The lower orders of flowering plants also had a limited development. Thus there were conifers, which grew on the higher grounds, and whose nutlike fruits are sometimes found as fossils. These forms were not great in amount, and their upland situation was not favorable for preservation to future ages. Important changes came in the Permian time, especially in the approach to extinction of the Lepidodendrons and Sigillarians.

351. **Animal life of the Carboniferous period.**—We now for the first time find a widely distributed and well-preserved fossil of the type of Protozoa. It has about the size and shape of a grain of barley or wheat, and the genus is known as Fusulina. It occurs in many Carboniferous strata, both

in America and in Europe. The student must not suppose that this was the first of the Protozoa. When it is remembered that great classes of these forms secrete no hard parts, and are in appearance little more than bits of jelly of microscopic size, their non-appearance in Paleozoic rocks will be the expected and not the surprising fact.

Corals are found, though more commonly in early Carboniferous times than afterward. But the Favosite group has disappeared, leaving but one of the three great types of Paleozoic coral in existence. Crinoids had an immense development in the deeper seas of the Early Carboniferous, but, as we should expect from their habit, are not abundant in the coal measures. According to Dana, 650

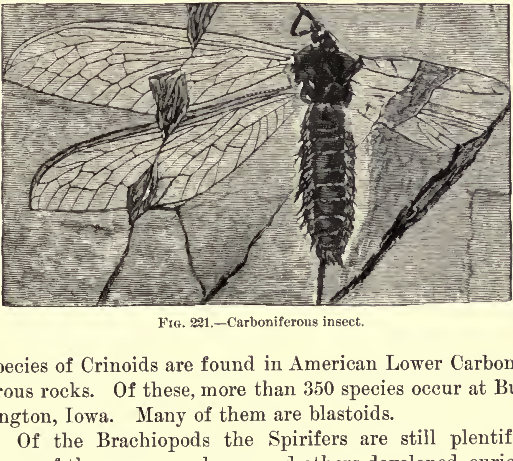


FIG. 221.—Carboniferous insect.

species of Crinoids are found in American Lower Carboniferous rocks. Of these, more than 350 species occur at Burlington, Iowa. Many of them are blastoids.

Of the Brachiopods the Spirifers are still plentiful. Some of them are very large, and others developed curious and almost fanciful shapes in their shells. Two hundred species of Spirifer are reported from Devonian and Carboniferous rocks, but they are few in the Permian part of the period. The irregularity of some of the Carboniferous forms seems to be a prophecy of their early extinction. Another great genus of Carboniferous Brachiopods is the spinose Productus, which first became conspicuous in the Devonian fauna. Mollusks begin to number land shells among their forms. This is the only significant change in this group. But three species of Trilobites are now left,

Fig. 222.—Productus Nebrascensis. Three views of a specimen from the coal measures of Illinois.

showing how near to extinction this great group of Paleozoic creatures has come. But more modern forms of Crustacea are multiplying. Spiders are added to scorpions, which had been so long present, and there are many flies, locusts, and cockroaches. There were none of the higher insects, as there were none of the higher flowering plants,

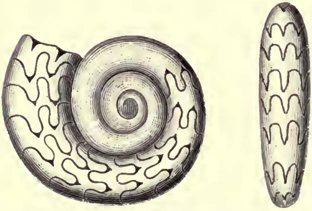


Fig. 223.—Goniatite, two views.

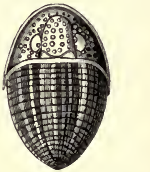


Fig. 224.—One of the last of the Trilobites.

these having in later times developed together, with the greatest modifying influence upon each other. The fishes are still of the ancient types. Amphibians, which are now believed to have appeared in Devonian times, are somewhat common, and reptiles begin in the Permian.

### Appalachian Revolution

352. The eastern interior has been, as we have seen, an area of deposits, and on the whole of growing lands since the beginning of Paleozoic times. The total thickness of the several Paleozoic systems of rock in the Appalachian belt is very great—not less than 30,000 to 40,000 feet. A great range or series of parallel folds was now made, extending from Catskill on the Hudson to central Alabama. Some facts about this range were given in the chapter on Physiographic Geology. Over much of the long tract of country extending from the Middle States almost to the Gulf, the mountains were of Alpine height. West of the mountains in Pennsylvania, West Virginia, and other States the former lowlands were elevated into a plateau. Up to that time some parts of the region had still been liable to incursions of the sea. The possibility of this now passed, and the eastern portion of the continent became, for the greater part, permanent dry land. With the great uplift denudation became extremely active. What the course of the drainage was, we do not know. It has been surmised that the uplift, extending far to the north and west, may have begun or caused a depression along the general course of the present Great Lakes and St. Lawrence River, or, roughly speaking, along the line of junction of the Paleozoic with the earlier formations. But if this is capable of proof, it has not yet been proved. In later periods some drainage history becomes better known. It is most important to emphasize the stupendous transfer of materials which now began to take place from the great mountain regions, toward the east, the south, and the west. We must not forget that this mountain uplift took place so slowly that the rocks affected were not commonly much metamorphosed. Nevertheless, geologically it was rapid and is entitled to be

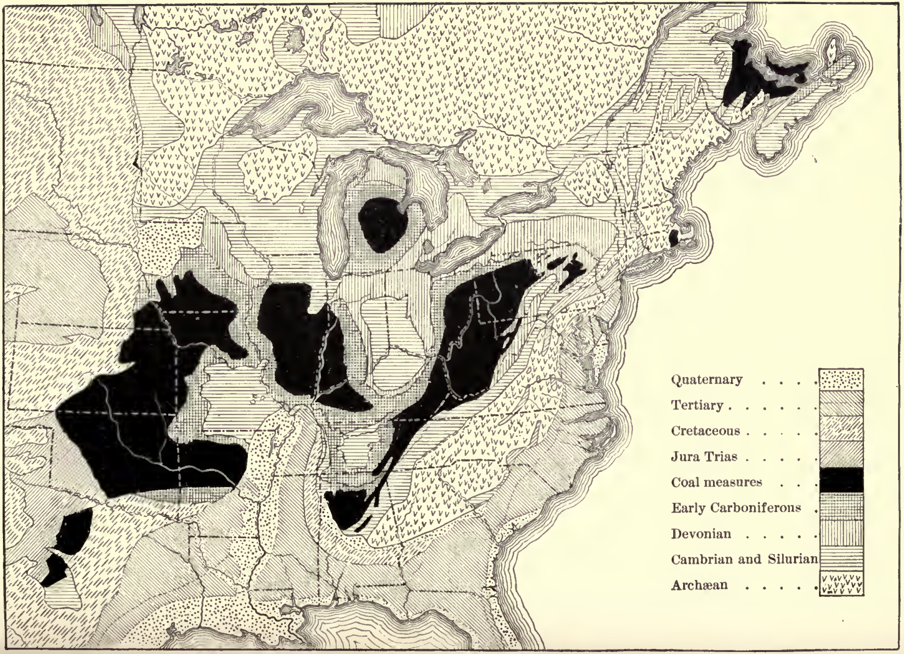



Fig. 225.—Geological map of the eastern part of the United States.

called a revolution. This designation is suitable for another reason. One of the greatest breaks in the life history of the world follows it, and it is no doubt due in large measure to the change of conditions and enforced removal of species from their former habitats.

The Atlantic shore line after the revolution is not known. We only know that some Mesozoic waters swept up to the base of the mountains in New Jersey, Virginia, and the Carolinas. Dana draws the post-Paleozoic shore line a little outside of the present Atlantic and Gulf shores, and then westward through Texas, eastern Kansas, and along the western border of Minnesota. West of that shore was sea, whose islands formed a skeleton of the future lands, much as they had in pre-Paleozoic days. The Rocky Mountains and Sierra Nevada were sketched in, and a great island lay on the Nevada-Utah border. In time to come eastern North America was to be a region of land sculpture with deposit on its fringe, but western North America was to be a theater of land-making through long periods.

## CHAPTER XXII

### MESOZOIC ERA

### Triassic and Jurassic Periods

353. The Mesozoic era is a great natural division of geological history. It is based primarily upon its life, which is intermediate between the ancient and modern groups. Some remnants of the old life survive, and there are abundant prophecies of the new, but the era has its own strong characters. It is often called the Age of Reptiles, because these were large in numbers and often of huge size. Some lived in the water, others on the land, and others could fly. Thus they ruled in all fields of existence. When we say this, however, we must remember that other creatures were abundant also. Corals and mollusks, and crustaceans, echinoderms, and fishes were as important as ever, though we may not always be able to find the strata which preserve them; just as the general life of the world did not stop when the Napoleonic armies were on the march, although the history of that period has much to say about them.

In geographical progress also in North America the era stands well by itself. We have already observed that eastern North America was chiefly the product of Paleozoic times. In the Mesozoic era, however, with the exception of a strip along the Atlantic and Gulf coasts, the principal land- and mountain-making was in the West. Triassic and Jurassic formations were first studied in Europe. They have thus far been found less typically developed in America, especially in the East. It will hence be better for us to take them up together. The life of the two periods is also sufficiently a unit in its great features to warrant such a treatment. The Triassic period is so named from a threefold grouping of its formations in Germany. The Jurassic period takes its name from the great succession of rocks and fossils in the Jura Mountains, which are outliers of the Alps between France and Switzerland.

### Triassic Rocks of Eastern North America

354. Students and teachers who live in the vicinity of these formations will find a full and interesting account of them in a Bulletin (No. 85) of the United States Geological Survey, by Prof. I. C. Russell. They are there, as often elsewhere, called the Newark Formation, from their occurrence about Newark, N. J.

They lie in a series of long patches in a belt on the southeast side of the Appalachian Mountain system, and extend, with breaks, from Nova Scotia into North Carolina. They consist mainly of sandstones, often varying into beds of conglomerate and shale, or less commonly into limestone. They do not contain marine fossils, and hence could not have been made along the borders of the open sea. They seem to have been deposited in hollows or basins filled with fresh water, or in great estuaries with brackish water, largely protected from the sea. Very coarse conglomerates are sometimes found, even with bowlders two or more feet in diameter, raising the question whether glaciers may not have supplied them from the adjacent mountains. But there is no conclusive evidence of this. We must remember that the mountains were yet young, and their torrents were powerful, like those of the Alps to-day. The materials in the beds show that they came from the pre-Paleozoic crystalline rocks of the older Appalachian axis. Hence the drainage of the Appalachian folded area of Paleozoic rocks must still have kept its original northwest direction. The change had not yet come by which the Susquehanna, Potomac, and other waters should descend toward the Atlantic.

During the period of deposition, or, as some think, at its close, there were large volcanic outflows forming the sheets which were described on page 244. A brief account of the principal areas will now be given. The Acadian area lies in northern Nova Scotia. One of the most interesting lies in central Connecticut and Massachusetts, and has been carefully studied for many years, especially by Hitchcock and Emerson of Amherst, Dana of Yale, Davis of Harvard, and Percival of the early Connecticut Survey. The rocks occupy the region of an old bay or sound which extended from the sea at New Haven over the sites of Hartford and Springfield to the northern border of Massachusetts. On either hand lay the mountainous uplands built largely of Paleozoic formations. The materials of these older rocks can be identified in the younger beds. Probably the tides rose and fell on the shores, and it is certain that land reptiles, amphibians, and insects dwelt in great numbers about, for these ancient surfaces have yielded thousands of specimens of tracks, formerly thought to be those of birds, but now known to be mainly reptilian. Slabs bearing remarkable series of these tracks are preserved in the Amherst and Yale Museums. Ripple marks, mud cracks, and rain-

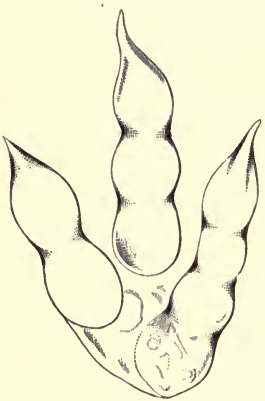


Fig. 226.—Track of Triassic reptile of the Connecticut Valley ($\times \frac{1}{8}$).

drop impressions prove beyond doubt that we have here a splendid display of ancient shore surfaces.

The Triassic rocks of the Connecticut Valley do not lie as when made, but dip eastward from 15° to 25°. They are much broken by faults, so that their thickness is not known, but may be 5,000 to 10,000 feet. Interleaved between the strata are masses of lava. The prevailing view seems to be that at intervals during the deposition of the beds, sheets of lava were poured out, covering more or less of the bottom of the sound, after which they were covered by younger sediments. In some cases intrusive sheets were formed. They all shared in the uplift and faulting which came later. The denudation of the region has since cut away the softer sediments and left the outstanding lava beds to form Mount Tom, Mount Holyoke, and other eminences of the valley. These often have a steep slope of columnar lava on the west, and share the more gentle dip slope of the sandstones on their eastern face.

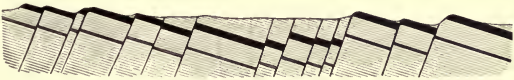


Fig. 227.—Section across the Triassic rocks of the Connecticut Valley, showing trap sheets (in black), faults, and outstanding of trap after denudation.—After Davis.

So many main features are repeated in the several areas that the rest may be more briefly described, although the largest is yet to be named. This is called the Palisades area, and extends from Haverstraw on the Hudson through New Jersey, Pennsylvania, and Maryland into Virginia. It is 350 miles long. The Palisades of the Hudson are formed by the eastern outcrop of one of its great lava beds. Under it by the river and over it on the west slope of the ridge are the shales and sandstones. The Watchung Mountains near Orange, N. J., are of the same origin. The dip of the rocks in this area is westward. Several smaller but important areas from 35 to above 100 miles long lie in the same northeast by southwest line in Virginia and North Carolina. One of these is called the Richmond area. The coal of some of these southern patches will be noted in a later section. Little is known of the barriers which must have shut out the sea on the east of these troughs of deposition.

355. **Triassic rocks of the West.**—Rocks of this period are found in western Kansas, extending thence into northern Texas. The Black Hills of Dakota consist of a pre-Paleozoic core, with Paleozoic and later strata dipping off under the plains in all directions. Triassic beds are included in the series here. Along the base of the Front Range in Colorado, Triassic strata make part of the formations whose broken edges are turned up against the mountains. The slabs and pillars of the Garden of the Gods are reckoned as Triassic. We have here part of an extended series known as the Red Beds. They are also seen in the same relative position as one crosses the Rocky Mountain belt and comes down on the west slope in Colorado. Triassic rocks form the Vermilion Cliffs of the Colorado plateaus, and are found in western Nevada and northern California. These far western Triassic rocks contain some limestone, and, unlike other American Triassic, are marine.

No marine Triassic or Jurassic rocks are known in the Atlantic or Gulf belts, but the Cretaceous or later Mesozoic beds abut against the pre-Mesozoic formations. This shows that during Triassic and Jurassic times the land was higher, the Atlantic shore farther east, and the Gulf shore farther south. Later the land sank and Cretaceous seas with their deposits crept to the base of the highlands in New Jersey and southward.

356. **Western Jurassic rocks.**—As in the case of the Triassic, so the Jurassic beds outcrop about the Black Hills and along the flanks of the Rocky Mountains. We have seen that a large area of Paleozoic land existed in the Great Basin region. This and the Rocky Mountain belt were the chief centers of growth for the western lands. On the

east of the Great Basin land deposition went on, and Jurassic outcrops are now found in the Wasatch Mountains and the Colorado plateaus. The region of the latter became a great secluded sea opening on the south, but yet to receive a vast series of Cretaceous and younger rocks. On the west also, along the then existing Pacific border in eastern California, deposition went on. Jurassic shales, soon (soon in a geological sense) to be elevated to form part of the Sierras, became after metamorphism the gold-bearing slates of California.

357. **Elevation of a Sierra Nevada mountain range.**—This is now known to have occurred at the close of the Jurassic period. A great series of rocks had been long accumulating on a sinking sea floor, precisely as in the eastern Interior Sea in Paleozoic times. At length the pressure made itself felt in crushing and folding, and we have now three great mountain ranges in various stages of development. The Appalachian was finished, save as it should be affected by denudation. The Rocky Mountains were outlined, but their chief growth was to come later. The Sierras were well under way, but were to receive a vast addition to their height by faulting and uplift in later times. Their development at the close of Jurassic time is sometimes called the Sierran Revolution. It is also believed that the upheaval of the Coast Range of California was coincident with the making of the Sierras, thus outlining for the first time a gulf where now runs the Great Valley of California.

## Life of the Triassic and Jurassic Periods

358. **Plants.**—The forests were losing some of their ancient characters, but had not yet taken on a modern appearance. The Lepidodendrons and Sigillarians, which were so common in the Carboniferous period, now became insignificant. But the higher Cryptogams are still represented by the Ferns and Horsetails, and the Gymnosperms furnish abundant examples of the two great orders, the

FIG. 228.—Branch and fruit of Conifer.

FIG. 229.—Cone of Jurassic pine.

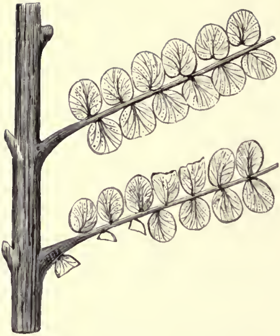


FIG. 230.—Triassic fern, from Richmond coal.

FIG. 231.—A living Cycad.

Conifers and Cycads. The Conifers, as we have seen, came over from Carboniferous times. The Cycads are palmlike in appearance but not in structure, and form the most characteristic element in Mesozoic vegetation. As yet there were, at least so far as is known, no Angiosperms or higher flowering plants.

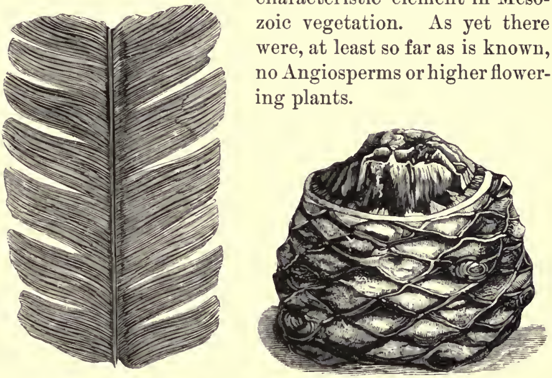


FIG. 232.—Leaf and stem of Jurassic Cycad.

359. **Animals.**—As a rule, American and European Triassic rocks are poor in fossils, owing to special conditions of deposit in waters more or less disconnected from the sea. Jurassic life is much more abundant both in western America and especially in Europe, where marine waters were again extensive. Jurassic rocks in some localities preserve many Foraminiferan and Radiolarian shells and a great profusion of sponges. It will be remembered that we have already met with Foraminifera in the Fusilina of Carboniferous strata. Hydrozoa are known to have lived, from quite perfect impressions of jellyfish found in the limestones of Solenhofen, Bavaria, and now to be seen in the museum at Munich. Corals also are numerous in the Jurassic. One after another the Paleozoic patterns have disappeared, and these forms now take on a modern structure, having their rays or radial partitions in multiples of six.

Several strata of the English Jurassic were thickly set with them, showing that these northern waters were still warm, and reefs like those of Florida and the Bermudas were growing there. There were more than two hundred species of British Jurassic corals. The same conditions were found in central Europe, in the region of the Jura Mountains, and portions of the future area of the Alps.

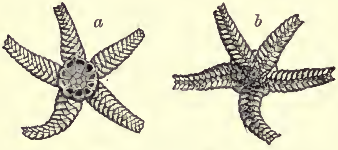



Fig. 233.—Triassic starfish, dorsal (*a*) and ventral (*b*) surface.

We must again note the entire disappearance of the Paleozoic Cystids and Blastoids, and the change of the true Crinoids into the modernized patterns. The Echinoids, or Sea Urchin group of Echinoderms, had attained some development in the Paleozoic era, but now grew in

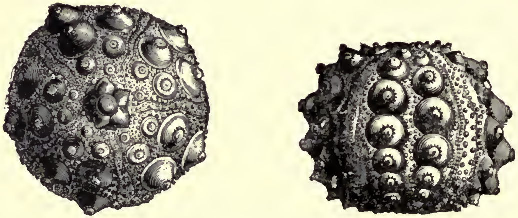


Fig. 234.—Jurassic sea urchin.

numbers and in resemblance to existing forms. Some, for example, become elongated and unsymmetrical, with mouth at one end, instead of having the mouth below, as in the common sea urchin. These unsymmetrical forms belong to the Spatangoids.

Many changes had occurred in the Brachiopod group during the Paleozoic periods. On the whole, they had become less conspicuous, though still numerous in the Carboniferous period. We have now to record a still greater diminution in their ranks. The Lingula, Discina, and Terebratula were all Paleozoic families of greater or less antiquity, which lived in Jurassic seas and still live to-

FIG. 235.—Jurassic oyster.

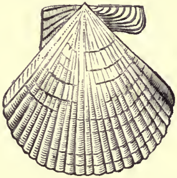


FIG. 236.—Pecten, Triassic.

day. But there were no more Spirifers, Atrypas, Orthis, or Productus, of which such countless hosts had lived in Paleozoic days. The Brachiopods have steadily waned through the millions of years, and the mollusks have as steadily grown, but with new families, genera, and species.

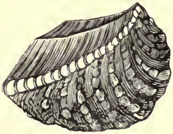


FIG. 237.—Trigonia, Jurassic.

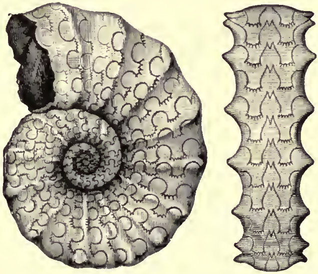


FIG. 238.—Ceratites, showing the suture lines simply crimped.

Some existing genera of Lamellibranchs now appear, but with different species from those in present seas. Thus there are several kinds of oysters, some of large size. Other forms are Pecten, Astarte, and Trigonia. It will give some idea of the number of Gastropods to note that nearly 1,000 species lived in the Jurassic seas of Britain. The most conspicuous feature of Jurassic and of all Mesozoic molluscan life is the group of Cephalopods. There had been a steady decline in the Nautiloid group of straight and curved shells, and the Ammonoid group were on the increase. These are the forms characterized by increasing complexity of the transverse partitions. This begins to show in the Goniatite of the Devonian, is more fully seen

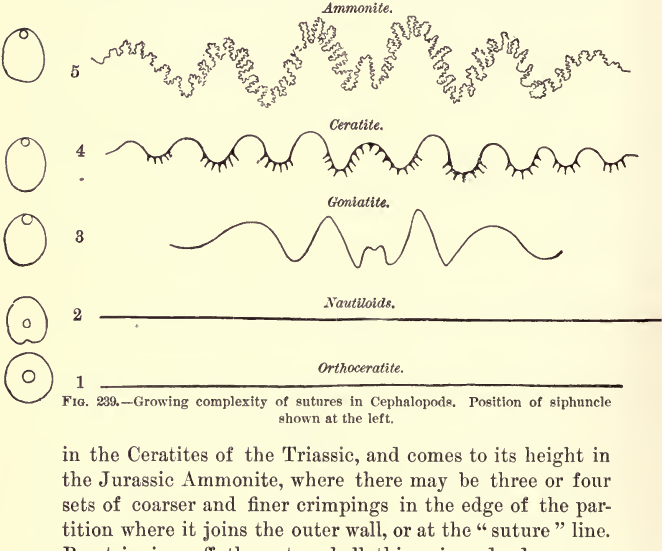



FIG. 239.—Growing complexity of sutures in Cephalopods. Position of siphuncle shown at the left.

in the Ceratites of the Triassic, and comes to its height in the Jurassic Ammonite, where there may be three or four sets of coarser and finer crimpings in the edge of the partition where it joins the outer wall, or at the "suture" line. By stripping off the outer shell this crimped edge comes to view. This series of more simple and more elaborate forms is of great interest, not only because seen in passing from older to younger strata, but because it marks the path of development of the elaborate forms, from the embryo to the mature state. The individual in its growth displays the same succession as is manifested by the ancestral series in its development through long periods. Embryologists and paleontologists have found that this is a great principle of organic life, and it becomes, therefore, one of the most impressive proofs of the origin of the various patterns of animals and plants by development from ancestral forms.

These Jurassic Ammonites are in great number of species and variety of ornamentation. Hundreds of species are recorded, and some are of large size, even two or three feet in diameter in a few cases. This high state of development seems to be the precursor of decline, for they disappear by the close of the Mesozoic era. But the naked Cephalopods, or

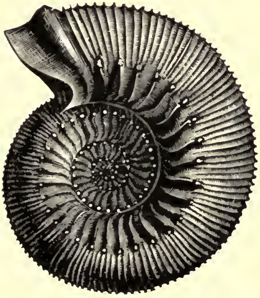


Fig. 240.—Jurassic Ammonite.

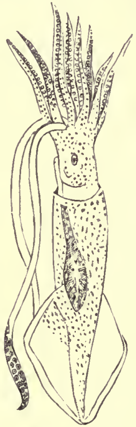


Fig. 241.—A living cuttlefish.

Fig. 242. — Belemnite, internal shell.

those without external skeletons or shells, were already coming in, the squids and cuttlefishes, to dominate the group in later and modern times. Some of these fossil forms are called Belemnites, from a rounded and elongated internal rod or bone. They possessed ink bags, like the modern cuttlefish. These are sometimes preserved in remains of the ancient species. It is an often-repeated but nevertheless interesting observation in textbooks that drawings of fossil forms have been made with their own ink. The ancient shelled Cephalopods are called

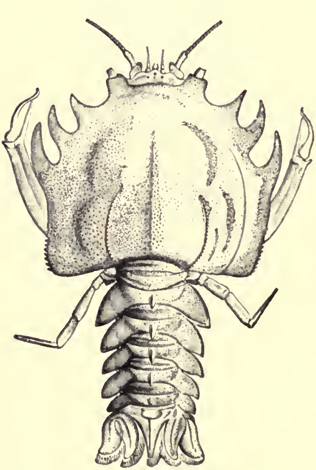


Fig. 243.—Jurassic Crustacean.

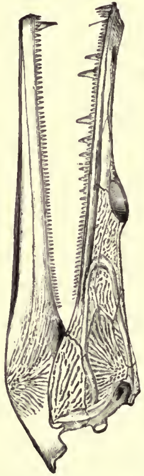


Fig. 244.—Jaw of Triassic amphibian.

Tetrabranchs, and the modern naked forms are Dibranchs, from their having respectively four and two gills.

Of the Crustaceans there are no more Trilobites, and modern crabs and lobsters begin to come in. The Insect group also becomes modern in fullness and variety, including most of the orders. A reported specimen of Butterfly is considered doubtful, the more because none of the Angiosperms or higher flowering plants have yet been found in rocks as old as the Jurassic.

360. **Vertebrates.**—Here, with the exception of the great host of Ammonites, we find the chief features in the life of the times. Thus the highest animal type for the first time becomes supreme in the world's life, a position which

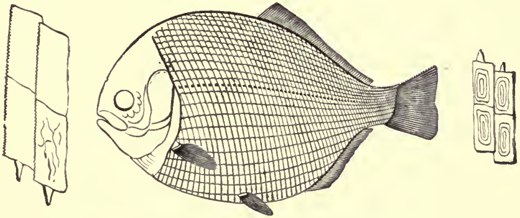


Fig. 245.—Jurassic Ganoid, with view of scales enlarged.

by one or another of its classes it has never ceased to hold. The Mesozoic character of the era is seen in its fishes, which still number the old Ganoids and sharks, but some of these approach in character the modern Teleosts, or fishes with bony skeletons. Amphibians grew in numbers and size from Carboniferous times, some of the Triassic forms being

Fig. 246.—Jurassic sea reptile, Ichthyosaurus.

large and powerful creatures, quite unlike the insignificant modern examples. One specimen has been described whose skull had a length of two feet. About 50 species of sea reptiles are known from the Jurassic. Two great types only are here named. One is Ichthyosaurus (fish lizard). It was sometimes 30 to 40 feet long, with a relatively large head set close upon its body, having long, powerful jaws and many sharp teeth. The eyes were enormous, the tail finned, and its limbs were two pairs of short, stout paddles. It quite realizes all traditions of horrid and vicious sea monsters. Twenty-five species of these creatures are known to have lived in the waters of Britain. Nearly 50 species also of Plesiosaurus are there found fossil, and the museums possess some highly perfect skeletons. The members of this group were more slender, but having a short tail and longer

FIG. 247.—Jurassic sea reptile, Plesiosaurus.

neck, and larger paddles also. The head was light, and the creature was fitted to rear and dart after its prey. Its greatest length was 25 to 30 feet.

The land reptiles were, if possible, more wonderful still, in size and habit. Some were by far the largest animals of all time in length and bulk. They are given the general name Dinosaurs, which means terrible lizard or reptile. Many lived on vegetation, but others were carnivorous. In comparison with their size their heads were very small. In some cases the nervous masses in their posterior parts for the control of their huge limbs were many times larger than their brains. Many had powerful and heavy hind limbs and tails, with light fore limbs as well as slender necks and small heads. This fitted them to move in part or altogether on two legs, or two legs and the tail. Thus the herbivorous kinds could readily reach up and crop or haul down leaves and boughs of trees. More strange still,

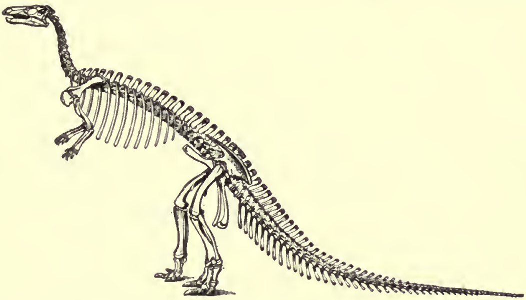


FIG. 248.—Jurassic land reptile, Camptosaurus ($\times \frac{1}{60}$), Wyoming.

the light fore parts and bipedal locomotion give many of these creatures a distinct resemblance to the birds, and support the general conclusion to which naturalists have come, that the birds and the reptiles have developed from a common ancestral stem. It will be useful to add a few

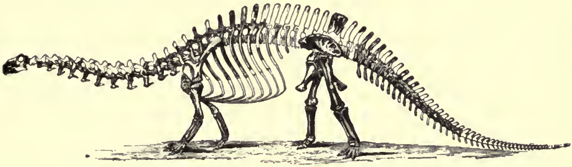


FIG. 249.—Land reptile, Brontosaurus ($\times \frac{1}{120}$).

facts as to the size of some of these animals. Brontosaurus was sometimes 60 feet long. The Atlantosaurus, found in the upper Jurassic rocks of Colorado, had a length of 70 to 80 feet. A single thigh bone was 6 feet long.

A single vertebra of another species had a diameter of 2 feet. Stegosaurus is remarkable for a series of huge bony plates mounted along the back. Thus we have immense size, a low grade of intelligence, with fantastic and exaggerated structures as somewhat common characters. In

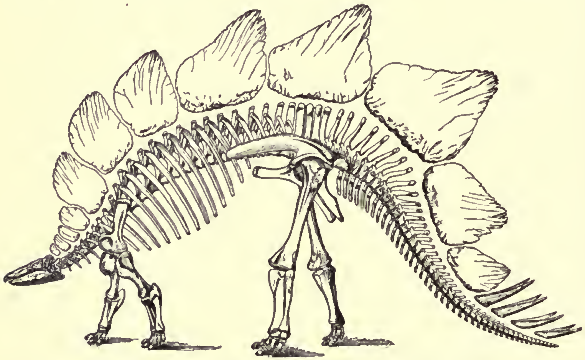


Fig. 250.—Jurassic land reptile, Stegosaurus ($\times \frac{1}{80}$), Wyoming.

some way flowing from these facts, it may have come that the group lacked stability. They perished with the era to make way for higher and nobler types.

A reference to their geographic distribution should be added. Most of the larger tracks of the eastern American Triassic are those of Dinosaurs, notwithstanding their three-toed impressions, a fact which again is of interest, because they were formerly thought to have been made by birds. It is somewhat surprising that the tracks should be found in thousands in a region which has yielded none of the skeletons. On the other hand, the Jurassic beds of Colorado, Wyoming, and Montana have yielded a great harvest of Dinosaurian bones, which have been found and amply studied by Marsh, Leidy, Cope, Scott, and other American scholars.

As if these curious creatures were not enough to give individuality to the time, we find also flying reptiles, to which the name Pterosaurs has been given. These were small, but had a remarkable combination of bird and reptilian characters. The bones were hollow like those of a bird, and the head was light but large, and the jaws armed with teeth. There were no feathers, but the finger occupying the place of the little finger was greatly lengthened, and between it and the body and rear limbs stretched a membrane serving as a wing. Sometimes there was a long,

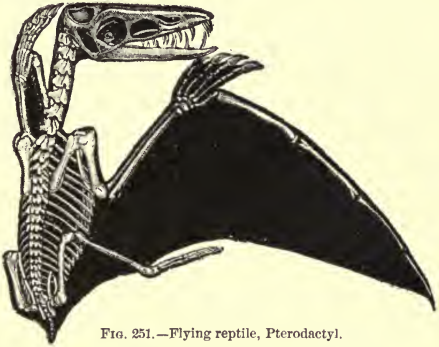


Fig. 251.—Flying reptile, Pterodactyl.

slender tail ending in a flap. The lithographic limestones of Bavaria have afforded examples that leave no doubt of the nature of this creature.

The Pterosaur is a birdlike reptile. The next step is a reptilian bird, and these have been found in the same locality with a reptilian head, feathered wings, and a vertebrated tail, with feathers on either side of it to the end (Fig. 252).

We have seen that many forms, as the Trilobite, numerous Brachiopods, and types of coral, passed out with the Paleozoic. Some typically Mesozoic forms, as Cycads and reptiles, are at their height. We come now to a modest but significant prophecy of the modern periods of the

FIG. 252.—Jurassic bird, Archæopteryx (× ¼).

earth, the beginnings of the mammals. A few remains of very small and lowly creatures of this class have been found both in Triassic and Jurassic strata of America and Europe. Their great interest lies in the fact that we have here the first examples of the group to which man and all the higher animals belong.

361. **Economic products.**—Several substances are found in Triassic and Jurassic strata which have well served the needs of man. Triassic sandstones form most of the "brownstone fronts" in New York and other cities of the East. They have for many years been quarried at Portland, Conn., East Long Meadow, Mass., and in other places. They appear well, but are not especially durable when set as small pillars and window bases, or in other exposed positions. The "Peachblow" sandstones seen in some of the buildings of Colorado College are from the "Red Beds" of Triassic age in that State. Several references have already been made to the remarkable deposit of fine-grained limestone of Jurassic age at Solenhofen in Bavaria. It is almost unique in its perfection for lithographic reproduction.

The Triassic coal beds of Virginia and North Carolina are of considerable value, though their importance has been obscured by their nearness to the vast deposits of Carboniferous times. Eight coal beds occur in the Richmond area, and some are of considerable thickness. Thin beds of coal of more geological than economic interest occur in the Triassic of Germany and the Jurassic of Great Britain.

In both these countries are found beds of rock salt of the same period. By the upturning or fracturing of Jurassic shales in the Sierra Nevada Mountains, veins of quartz were formed which are rich in gold. Thus these shales became the "auriferous slates" of California. The Placer deposits (page 240) are produced by the erosion of these slates, and the veins themselves have yielded enormous values of the precious metal.

# CHAPTER XXIII

## MESOZOIC ERA

### Cretaceous Period

362. **General observations.**—This period takes its name from the chalk which constitutes important strata in some countries, especially in England, where the name was first applied. The most conspicuous changes in the living inhabitants of the world were the growth of Angiosperms, including forest trees of modern kinds, and the presence of Teleosts, or bony fishes, in the seas. It is usual to reckon two divisions of time, as determined from the succession of rocks, an early and a late, Cretaceous period. The areas of deposit in different parts of North America were so remote from each other and so separated by land masses, that geologists have had trouble in making out equivalent beds. As is usual, the strata have been given local names, and so we have one set of designations for the Cretaceous rocks of the Atlantic coastal region, others for the Gulf region east and west of the Mississippi River, a different set for the country between the Mississippi River and the Rocky Mountains, and still another for the Pacific coast.

363. **Geography of the Cretaceous period.**—The student will best get a general notion of what happened in Cretaceous times if he at once takes account of a great downsinking and uprising which affected most of the continent. During early Cretaceous time the land was high, the shores receded, and there were areas of fresh water along the present belt of Atlantic lowlands and east of the Rocky

Mountains. The exception to this was over Texas and parts of Indian Territory, Kansas, and New Mexico, where a marine bay stretched northward from the Gulf of Mexico. Before the middle of the later Cretaceous the sea on the east had swept up to the base of the highlands in New Jersey and the States lying southward, as shown by marine Cretaceous rocks now found there. Thence the shore line

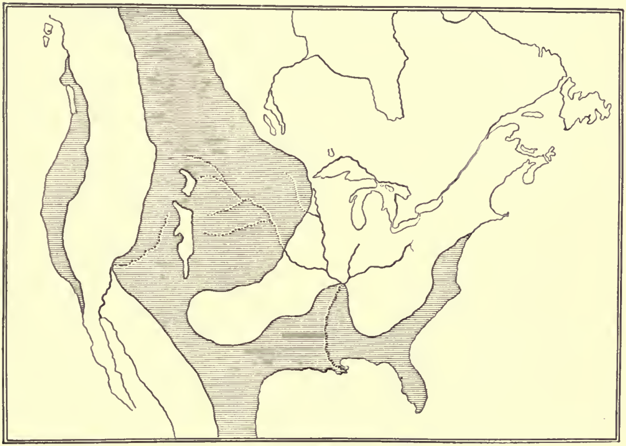


Fig. 253.—North America, showing probable land areas during the Cretaceous submergence. Water areas shaded.—After Le Conte.

swung around to the west and crossed the middle of Georgia and Alabama and retreated along the present valley of the Mississippi to southern Illinois, whence it stretched southwestward into Texas. The area of the Delta and of hundreds of miles of the present flood grounds of the Mississippi was then occupied by an arm of the sea. Farther west the open sea again swept through, as is believed, from the Gulf to the arctic regions, and westward beyond the west boundary of Colorado. The Rocky Mountain nucleus was again reduced to a group of islands as in Paleozoic times. The lands of the Great Basin, however, stretching north into British America and south into Mexico, still separated this interior sea from the Pacific Ocean.

As the continent slowly came up again during the later part of the period, the great Western Interior Sea was narrowed and made shallow, the connection between the Gulf and the arctic seas was interrupted, lakes of fresh water, swamps and bays with brackish water, took the place of the ocean, and vast quantities of vegetable matter were formed in the marshes of this closing or Laramie epoch. This was the great coal-making time in the western United States. But simple emergence was not all. The way was preparing for the Rocky Mountain revolution, which occurred at the close of the Cretaceous period, and thus marks off both Cretaceous and Mesozoic time from all that follows in American geological history. Here is included the elevation of the Rocky Mountain range, from Colorado far northward and southward, and of the high and massive Wasatch Range, between the Great Basin on the west and the Colorado plateaus on the east. There were extensive volcanic eruptions also at various points in this great belt of disturbance. It is possible to determine clearly the time of this mountain-building. Cretaceous deposits with marine fossils are found at an altitude of 10,000 feet upon the mountains. The region must have been below the sea level until after the strata were made. The disturbance was therefore post-Cretaceous. But the succeeding rocks of the early Tertiary period lie unconformably against the upturned strata of the mountains, and have not suffered disturbance. The movement was therefore pre-Tertiary.

The continent was beginning to take on its modern form. The Appalachian, Sierran, and Rocky Mountain revolutions have passed, although uplift and denudation have yet much to do with their final form. The Eastern

Interior Sea was obliterated with the Carboniferous coal swamps and the Appalachian upheaval, and the Western Interior Sea disappeared, save for some great fresh-water lakes after the Laramie Coal epoch and the Rocky Mountain upheaval. The West and East were joined, and the heart of the lands was not to be again invaded by the sea.

364. **Cretaceous peneplain.**—Physiographers and geologists who have given attention to the subject, nearly all believe that a great peneplain was developed in the Eastern United States during Mesozoic times, coming to an advanced stage of development in the Cretaceous period. Allusions have already been made to parts of this surface in the chapter on Physiography. Such are the highlands of western New England and central New York. The even sky lines and other evidences of the existence of this peneplain are found in Pennsylvania and far southward along the Appalachians. After the Appalachian revolution, vast denudations went on throughout the long Mesozoic periods. The land waste was carried east, west, and south, and a great series of drainage modifications took place, into which we can not enter here, save to remark that, in some way not yet clearly known, the northern Appalachian drainage was reversed and turned toward the Atlantic. We are chiefly here concerned with the destruction of the mountains down to their roots, and the formation of the lowland surface, with its remnant mountains and hills. After Cretaceous times the peneplain rose to its present position. Reference to this, however, will be made in the following chapter.

365. **American Cretaceous rocks.**—A brief review of these will be given, especially to show the reality of the geographic changes described in the preceding section. The Cretaceous system in America is really much more full, both East and West, than that of the Jura Trias. The lowest Cretaceous rocks along the Atlantic border were deposited in fresh water and are known as the Potomac for-

mation. They consist of sandstones, conglomerates, and clay beds. Nothing is known of the barriers which must have separated the waters that received them, from the open sea. Beds of corresponding age are known as the Tuscaloosa group in Alabama on the old Gulf border and the Kootanie beds in the Rocky Mountain region, Montana, Dakota, and Canada. All point to a time of elevation and isolated belts of fresh water.

In the gulf that in early Cretaceous time stretched from Texas to Kansas a great body of rocks, mainly of marine limestones, was laid down. They are known as the Comanche series. They include beds of chalk, like those of Europe. The early Cretaceous of the Pacific border, west of the new Sierra range, was also marine.

Returning to the East, we find the upper Cretaceous rocks with more or less interruption exposed from Martha's Vineyard through the Carolinas. They are found on Block Island, Long Island, Staten Island, and in the States of the coast line. From central New Jersey, south, they lie west of a belt of overlying Tertiary rocks, which are between the Cretaceous and the present sea border. They are chiefly marine, and consist of unconsolidated sands, clays, and marls. Overlying the Potomac fresh-water beds as they do, they prove the submergence noted in our account of the geographic changes. Ripley group, Rotten limestone, Eutaw beds, and Tombigbee sands, are names given to the later Cretaceous beds of the Gulf border. In the Rocky Mountain region the rocks give most interesting proof of submergence followed by emergence. Four epochs are distinguished, with corresponding formations. They are the Dakota (sandstones and clays), Colorado (limestones, marls, shales, and sandstones), Montana (shales and sandstones), and Laramie (sandstones and conglomerates). Of these, the first is a fresh-water formation, the second and third are marine, and the fourth is fresh water—the Coal period of the West, as already said. Interested students will find accounts of these formations in Dana's Manual of Geology, and a great body of description in the Government surveys of the past thirty years. The rocks cover wide areas of the "Great Plains," and some of them outcrop for long distances about the base of the Rocky Mountains. Marine Cretaceous rocks were made on the Pacific border, the coast line running through central California, west of the Sierra Nevada, and northward across Oregon and Washington.

366. **Life of the Cretaceous period.**—The most remarkable progress is here seen in the vegetation. Fields and

Fig. 254.—Leaves of Cretaceous trees—oak, sassafras, and beech.

forests begin to look like modern times, because trees and flowers appear like those which are common to-day. This is especially true of the Laramie epoch, which is truly a time of transition from Mesozoic to Cenozoic times. In Europe there is an important break in the record between the two eras. This gap was bridged over in an interesting way by the finding of the Laramie strata. In like manner other obscure or unknown chapters of geological history may become accessible through future discoveries. The general principle of continuity in Nature is thus emphasized.

Accordingly, students of Laramie plants have inclined to place the epoch at the beginning of the Cenozoic era, but it has been retained as the closing epoch of the Mesozoic, because of the general resemblance of its animals to the older groups. The change in the plants begins earlier, however. One fourth of the plant species of the fresh-water Potomac beds, lying at the base of the Cretaceous in the East, are Angiosperms (75 species out of 300), while the Ferns, Conifers, and Cycads hold over from the Jurassic period. Here also are found Sequoias, the great trees of California, which have also been found in the Kootanie beds or early Cretaceous of British America, and in Greenland. We have here a single illustration out of the multitudes, to show how the distribution of living forms varies with climate, with the extension and height of the lands, and all other geographical conditions.

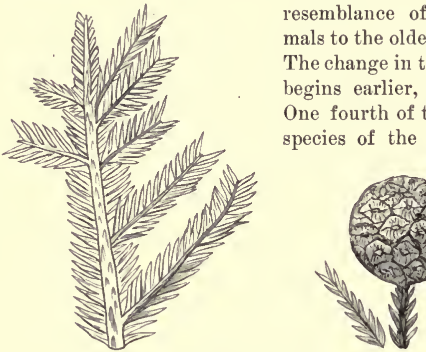


FIG. 255.—Branch and cone of Sequoia.

In the later Cretaceous the number of existing forms is greatly increased, and elms, maples, beeches, willows, sassafras, and birch are common. Gay Head on Martha's Vineyard, Long Island, and New Jersey are some of the Eastern localities where the remains of these modern trees have been found; the most important conclusion which is drawn from the character of the Cretaceous flora is that warm climates were still widely prevalent. Subtropical

FIG. 256.—Forest of late Cretaceous times.

temperatures like those of the Carolinas or Cuba extended over much of North America and Europe, and far away to northern Greenland.

367. **Animal life of the Cretaceous period.**—In some of the great groups the changes were rather in details than in the chief patterns, and hence need not detain us. The Protozoa now assume a recognized importance as rock-makers, since the chalks of Texas and of Europe are largely

composed of their minute shells. Chalks to the thickness of 1,000 feet are found in Europe. This fact bears testimony to the countless numbers of the organisms, as well as to the prolonged time required. It is by thus appreciating the time needed to make the rocks of a part of a single period that the student can at length in an imperfect way realize the meaning of geological time as a whole.

Fig. 257.—Section of chalk rock much magnified, showing Protozoan shells.

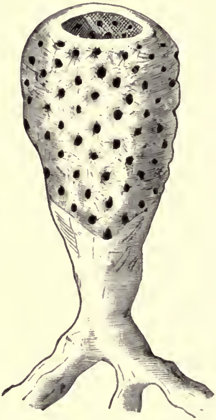


Fig. 258.—Cretaceous sponge.

That sponges were abundant in some seas is evident,

Fig. 259.—Foraminifera from chalk of Iowa (× 100).

FIG. 260.—Inoceramus.

FIG. 261.—Gryphæa.

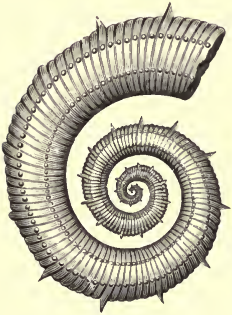


FIG. 262.—An open-coiled Cephalopod, Crioceras.

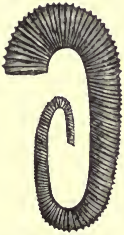


FIG. 263.—An irregularly coiled Cephalopod, Hamites.

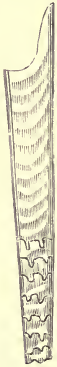


FIG. 264.—A straight Cephalopod shell, Baculites. This is like Orthoceras in general form, but has septa of Mesozoic type.

FIG. 265.—A high-coiled Cephalopod shell, Turrilites.

both from actual specimens and from the vast quantities of silica in the flint nodules of the chalk. Only occasional fossils of corals are found either in American or European Cretaceous rocks. Great numbers of most perfectly preserved sea urchins have been obtained from the chalk rocks of Europe, and they form some of the most attractive and beautiful displays in the museums.

The Mollusks were perhaps as abundant in the seas as they are now. A number of large Lamellibranchs are numerous and very characteristic of the Cretaceous. Such are Inoceramus and Gryphæa. These are genera of the oyster family. The Ammonites and Belemnites continue in great numbers from the Jurassic, and the Ammonites show interesting variations of form, which perhaps denote degeneracy, for this great Mesozoic group disappears at the end of the Cretaceous period. Thus we have Crioceras, which is an openly coiled shell (Fig. 262); Hamites, which is partly coiled and partly straight; Turrilites, which has a high coil, after the manner of some Gastropods; and Baculites, which returns to the straight form of the Orthoceras, but retains the complicated septa.

Some additions to the vertebrate group will be briefly noticed. Perhaps chief among these is the development

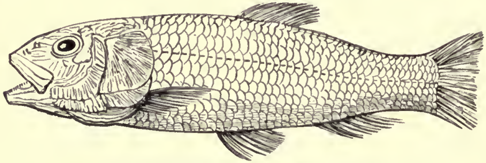


Fig. 266.—Cretaceous fish.

of bony fishes and the retirement of the Ganoids to a minor place. During at least four periods the latter group had been numerous and supreme among their kind. As in Jurassic times, the reptiles continued to rule the liv-

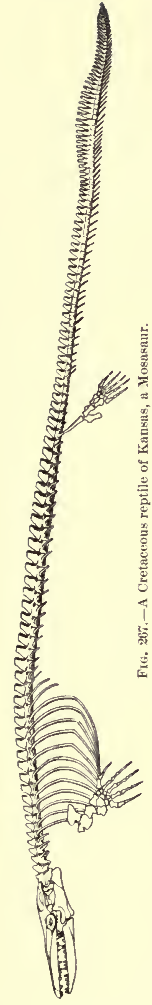


FIG. 267.—A Cretaceous reptile of Kansas, a Mosasaur.

ing inhabitants of the earth, air, and sea. The Mosasaur is a new form, of which many species have been found in western America, especially in Kansas. They were extremely slender, resembling both the lizards and the snakes, and were sometimes 75 feet long. They were typical and dreadful sea serpents. Snakes were few, but lizards and crocodiles were common. Some flying reptiles of Cretaceous age had a breadth of over 20 feet when their wings were spread. A great addition to the known bird fauna of American Cretaceous rocks was made by the discoveries of the late Professor Marsh, of Yale University. Some had teeth like the Jurassic birds, but others had none. Some had but rudimentary wings, and accomplished their movements by their long and strong limbs. They varied in size, from small birds to those having a height of 6 feet. The mammals do not effect any marked advance during the period.

368. **Economic products of the Cretaceous period.**—Much the most important of these in America is coal. The Laramie coal fields of the western United States are believed to cover 50,000 square miles. To this epoch belong the coal fields of western Kansas, New Mexico, Colorado, Wyoming, and Dakota.

So far as known, the Laramie coal is all bituminous, except in the vicinity of the Elk Mountains, west of the Continental Divide, where subsequent mountain-building has metamorphosed the beds into anthracite. Cretaceous coals are found also in Europe, as in northern Germany, and other places on the Continent. In New Jersey the marls are used as a fertilizer, and some of the clays are of a superior quality for the making of pottery.

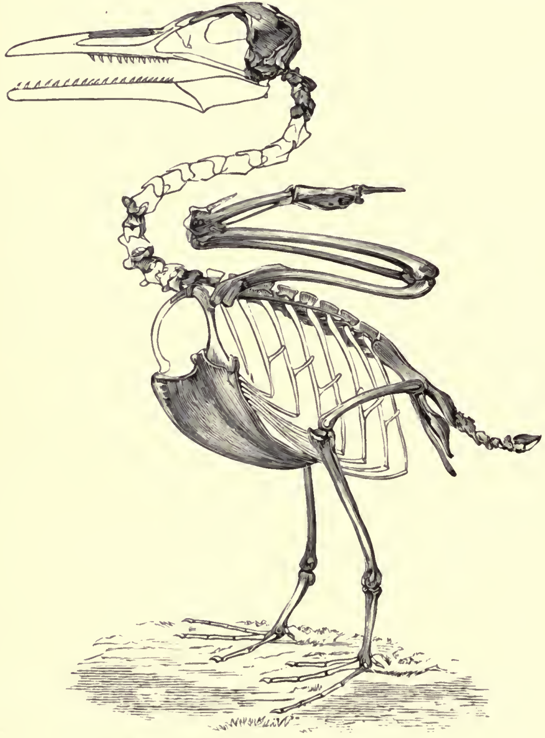


FIG. 268.—Cretaceons bird, with teeth (half natural size).

# CHAPTER XXIV

## CENOZOIC ERA

### Tertiary Period

369. We now enter upon the last of the great eras of geological history. It is, as its name means, the era of new or modern life. The higher vegetation introduced during the Cretaceous period continues, and grows in abundance and variety. The great reptiles have disappeared and the mammals become supreme. From the beginning of the era a growing number of invertebrate species are found, which live on until the present time. Geographically also, the continents are approximately of their present size and form. Especially is the Tertiary the period in which the great mountains of the Old World—the Pyrenees, Alps, and Himalayas—are upraised.

We divide the Cenozoic era into two periods, the Tertiary and the Quaternary, or Pleistocene. The name Tertiary survives from the earlier days of geology, when the succession of rocks with their peculiar characters was thought to warrant a numerical classification. The names Primary and Secondary have been discarded, and Tertiary is retained, because it is everywhere used in geological writings, and it is easier to keep it than to make a change.

370. **Tertiary geography of North America.**—In the eastern part of the United States, as we have seen, the long wear of the Mesozoic era had produced a vast lowland. From New York southward the early Tertiary seas swept in over the eastern part of the coastal States, covering with

newer beds of gravel, sand, and clay, most of the Cretaceous deposits. They covered the region of Florida, and the southern part of Georgia and Alabama, nearly as far north as in Cretaceous time, and swept up about to the mouth of the Ohio River. By the close of the period, however, the eastern part of the continent had risen higher than the position which it holds at present. To this culminating time of elevation belongs the elongation of the Hudson and other Eastern rivers, marked especially by the submarine channel of the Hudson, extending from New York across the continental shelf. The elevation also changed the Cretaceous peneplain into the plateau, now known by the various names of New England Highlands, Catskill Mountains, the Alleghany Plateau of New York and Pennsylvania, and the Cumberland Plateau, farther south. Gradually the plateau mass was dissected by streams and weathering with many modifications of drainage, the softer or more soluble rocks were etched out, and the hard beds left to show by their crest lines where the ancient peneplain had been. This, then, is the period of excavation of the Potomac, Kanawha, Susquehanna, Lehigh, Delaware, Hudson, and Connecticut Valleys. The history of the St. Lawrence River or of its ancient representative, for this period, and of the topography of the Great Lake region during Tertiary time, still remains in much obscurity. It is only when we come to the following period that the records become legible and full.

We have already seen that over most of the western United States the region of marine waters was past. After the Rocky Mountain or Laramie revolution, the region of the Great Plains was truly a part of the continent. But it is still believed to have lain near the sea level, with the exception of the mountain ranges. The reason for this belief is found in the existence in Tertiary time of vast lakes of fresh water, both east and west of the Rocky Mountain range. In some of these lakes thousands of feet of strata were formed from the wear of the new-made mountains. It is not believed that these lakes could have existed with the plains or plateaus at anything like their present altitude. Some of them were drained by uplift with warping, as still shown by the inclination of the strata. The position of the greater lakes will be indicated in our review of Tertiary rocks.

During the Tertiary period the entire West rose by a slow oscillation or series of such movements by an average amount of several thousand feet. Thus the plateau where Denver lies is now more than 5,000 feet above the sea. Most of this height was gained by the gradual movements of the Tertiary period. Similar is the origin of the present altitude of the Great Basin. But there extensive faulting and elevation of fault-block mountains was going on. Similar dislocations occurred in Utah, forming its high plateaus; also in the Wasatch Mountains and the Sierra range. The latter range had been formed at the close of the Jurassic time, but late in the Tertiary period it received a great part of its present height by elevation along the line of a profound fault on its eastern side, where now is the steep front of the range. Taking into account the widespread Tertiary elevation of the Western country, Dana thinks that the land mass—that is, the amount of matter above sea level—was thereby increased at least tenfold.

371. **Volcanic activity in the Tertiary period.**—This is the most extensive of which North American rocks contain record, unless it be in pre-Paleozoic times. The lavas in various forms are widely distributed over the mountain and plateau regions of the entire West. Here belong the vast lava sheets of the Columbia and Snake Rivers in Idaho, Washington, and Oregon; the volcanic cliffs and peaks of the Yellowstone Park; the much-denuded lava sheets of Colorado, both east and west of the Rocky Mountains; the volcanic peaks and necks of New Mexico; the sheets of the plateau region in Arizona and Utah; the lava floods of

the Great Basin; and the splendid volcanic cones of California, Oregon, and Washington; Shasta, Jefferson, Hood, St. Helen's, and Tacoma. To the same period are thought to belong the great volcanoes of Mexico and the Andes. It will be seen that this period of stupendous outpourings was also the time of the great uplift of western America.

372. **Epochs of the Tertiary period.**—The more common division of Tertiary time, at least in America, is threefold, giving us the Eocene, Miocene, and Pliocene epochs. Eocene means dawn of the recent, and is applied to beds which contain but a small percentage, 5 per cent or less, of invertebrate species which are now living. If more of their species are living, up to one half, the beds and the epoch of their making are called Miocene, which means less recent (as compared with the following epoch). If more than 50 per cent are living species, the beds are called Pliocene, or more recent.

373. **American Tertiary formations of marine origin.**—As the western uplift of post-Cretaceous date shut salt waters out from the interior, the marine Tertiary rocks are confined to the Atlantic, Gulf, and Pacific coasts. The only known locality of Tertiary beds on the New England coast is on Martha's Vineyard. From New Jersey south, however, they overlie the Cretaceous strata, and form a nearly continuous belt of the coastal lowlands, sloping gently off beneath the sea, and widening from New Jersey to South Carolina. The Martha's Vineyard Tertiary is Miocene, and the Atlantic coast Tertiary chiefly Eocene and Miocene. Some beds of New Jersey Tertiary are composed of greensand, which consist largely of grains of Glauconite forming the internal casts of minute Foraminifera, the shells themselves having been removed by solution.

The Gulf deposits make a wide belt, including all of Florida, which, with Louisiana, is the last State to have been wholly under the sea. Some of the Gulf beds are called Lignitic, because they contain vegetable accumulations made in the swamps of the low-lying lands. Buhrstone, Claiborne, Jackson, and Vicksburg are other names of Gulf Eocene deposits. The Miocene epoch is represented along the Atlantic by three stages—the Chattahoochee, Chifola, and Chesapeake. The beds of the last are exhibited along the shores of Chesapeake Bay and of the tidal rivers entering the bay. The Lafayette is a doubtful formation of unconsolidated, coarse sediments extending along the South Atlantic and Gulf coasts, poor in fossil contents and referred doubtfully to the Pliocene and to the following glacial times. It should be noted that the majority of the Tertiary strata are unconsolidated, though there are many exceptions, especially among the calcareous deposits.

We now turn to the Tertiary rocks of the Pacific coastal belt. The Coast Range of the post-Jurassic time is believed not to have been a continuous height of land, but rather an elongated archipelago. Behind it, toward the Sierra Nevada, was a sea, stretching far north and south, where the great valley of California now lies. In this sea, about the islands and at the western base of the Sierra, Tertiary muds were deposited. Strata of Eocene age called the Tejon Series are now found at the eastern base of the Coast Range. Later strata of Miocene and Pliocene age are found on either side of the great valley and in the mountain masses of the Coast Range.

They extend north into Oregon and Washington. The Tertiary sea still extended up the lower Columbia Valley, and was larger than now in the region of Puget Sound.

374. **Fresh-water Tertiary deposits.** — These are quite comparable in interest and importance to the marine beds. The great lakes in which these strata were formed lay both east and west of the Rocky Mountains.* They were

* Professor W. M. Davis has recently argued that some of these so-called lacustrine deposits may have been made by rivers. See the Fresh-

not all contemporaneous, but succeeded one another in the several epochs of the Tertiary period. It will be remembered that uplifts and dislocations were taking place in this region. A lake might end its existence because its basin became full of sediments, or because its outlet had deepened its channel, or because the region was tilted and the lake waters gradually spilled. The following enumeration of the lakes follows Professor Scott, who has given prolonged study to their sediments and fossil remains. The Eocene lakes fall under four heads: (1) The Puerco, in northwestern New Mexico, extending over into Colorado; one of the smaller lakes. (2) The Wasatch Lakes, of which the principal one was of immense size, covering much of Colorado, Utah, and southwestern Wyoming. Scott gives its length as 450 miles and its greatest breadth as 250 miles. (3) The Bridger Lakes, partly following one another. One of these was north of the Wind River Mountains, and two others lay along the present line of the Green River, in Wyoming and Utah, north and south of the Uinta Mountains. Another was the Huerfano Lake, south of the Arkansas River in Colorado. (4) The Uinta Lake in Utah and Colorado.

The Miocene lakes are as follows, as represented by their deposits: (1) The John Day, covering a relatively small area in eastern Oregon. These beds include vast quantities of volcanic ash, which fell upon the waters as similar dust falls upon the sea to-day. (2) Loup Fork, in two stages—the Deep River, whose waters spread over parts of Montana, and the Nebraska, whose beds stretch from South Dakota into Mexico. Similar lakes existed in California, Nevada, and British Columbia. Pliocene lakes were formed in Texas, Kansas, Idaho, and Oregon. According to Dana, the area of the great Miocene lakes now

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water Tertiary Formations of the Rocky Mountain Region (Proceedings of the American Academy of Arts and Sciences, March, 1900).

inclines from an altitude of 6,000 feet on the west, near the Rocky Mountains, to 3,000 feet on the east. This is due to continental elevation with warping. These lake beds suffered vast erosion, leaving valleys, cliffs, and buttes in endless variety. The climate is dry, the rocky wastes are unproductive, and hence the name of "Bad Lands" is widely used of these regions.

It has already been intimated that the great mountain-making disturbances of the eastern hemisphere were of Tertiary age. The Pyrenees were raised at the close of the Eocene, and the Alps at the close of the Miocene. The precise age of the Himalayas is less well determined, except that it was after the deposits of the Eocene.

375. **Life in the Tertiary period.**—Angiosperms, Conifers, and palms made up the forests of the time as they do today. The extreme northern distribution of temperate and subtropical plants has been noticed above. In harmony with this a small Tertiary lake basin at Florissant, Col., has preserved the remains of a warm-temperate flora in a region which now is high and too cool for the raising even of grain.

Even more do the Tertiary plants of Europe indicate a warm climate. They include cypress, magnolia, figs, and palms, but the temperate forms began to prevail before the close of the Miocene epoch. From the Miocene of Oeningen, Switzerland, several hundred species of plants have been discovered. Of nearly 500 of these kinds Heer assigns more than one half to the subtropical and about one fifth to the tropical classes of vegetation.

376. **Animal life of the Tertiary period.**—The life of the seas was steadily becoming more like that of the present day. As we have seen in defining the epochs of the period, all its rocks contain more or less of existing species, but no land species have survived until now. This is a great principle. Land species change or become extinct sooner than marine, because the environment also changes much more.

On the lands, mountain barriers are raised and climates are revolutionized, and particularly in this case a great glaciation came on, while in the seas changes progress

Fig. 269.—Tertiary leaves and fruits.

more slowly and give time for migration. Not much need be said as regards the marine invertebrates. The Protozoa had come to their modern geological importance. So no doubt had the Corals, though the rock-making areas of a nearly completed continent were not favorable for them, and their more abundant relics are therefore beneath the

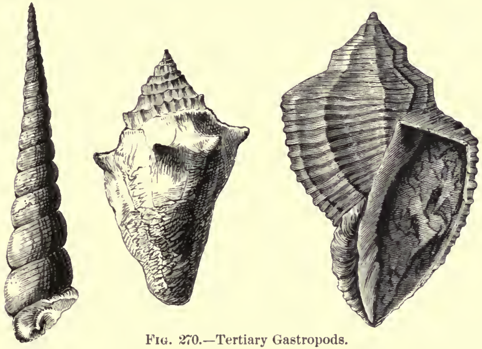

FIG. 270.—Tertiary Gastropods.

present seas. The Lamellibranchs and Gastropods looked like those of to-day, and the shells have suffered slight change since first buried in the sands and clays. Insects were apparently as abundant as now. They occur in the lake beds already referred to at Florissant, Col. Some of the shales are like leaves of coarse paper, and contain multitudes of fossil insects of all the great types, with large numbers of ants and plant lice. Another famous locality is in the Miocene of Oeningen, Switzerland, where it is reported that the alternation of seasons can be detected by the varying conditions of the plants in different layers. Toward 1,000 species of insects have here been found, including a great number of wood

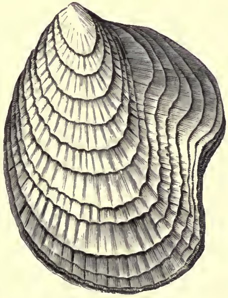

FIG. 271.—A Tertiary oyster.

beetles. Along the shore of the Baltic in North Germany, also, 2,000 species of insects have been found in amber, a fossil gum from ancient coniferous trees.

But it is the vertebrates which form the great feature of Tertiary life. The majority of the fishes are Teleosts, but some Ganoids remain, and the teeth of sharks are especially abundant in some marine deposits of the southern shores. A moderate number of snakes, turtles, and crocodiles are found, but the vast and characteristic forms of the Mesozoic era have all become extinct. The snakes have interest, because they are degenerate forms, having lost the limbs which their ancestors possessed.

377. **Tertiary mammals.**—It is these which dominate the period, which therefore is often called the Age of Mammals. In a manner which geologically is sudden, the reptiles waned and the mammals appear. The destruction of the reptiles was not due to the overmastery of the mam-

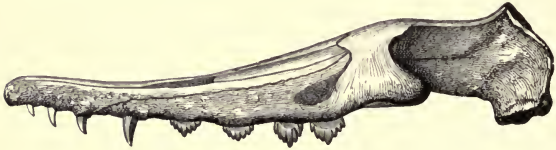

Fig. 272.—Jaw of Zeuglodon.

mals, but apparently to instability of constitution, or environment, or both. While the invertebrate species often pass on into the Quaternary period, the mammals change from epoch to epoch, and none of the species survive Tertiary time. The marine Tertiary of America does not abound in mammalian remains, which are found in marvelous numbers in the lake deposits of the West. Primitive whales, however, as would be natural, occur in the sea border deposits of the Atlantic and the Gulf. One of these is Zeuglodon, about 70 feet long, occurring in central Alabama. The name means *yoke tooth*, from the peculiar form of the tooth, and the bones were found in the greatest abundance, so much so that Dana suggests an earthquake shock, or some other catastrophe, as the cause of the sudden death in one place of so many of these creatures. The whale is another example of degradation, being a mammal, descended, as is believed, from ancestors which lived on the land. The Zeuglodon just noted is of Eocene age. Related species of whale are found in the Miocene strata of the Atlantic coast.

The Creodonts were Eocene creatures, flesh eaters, but combined the characters of true Carnivores and the insect eaters. As another illustration of the law that early forms are apt to be generalized, true Carnivores appear in the late Eocene. Early Miocene beds in western America show several of them, including early representatives of the panther, the dog, and the cat. Panthers, wolves, and tigers were plentiful in the late Miocene of the West. Rodents begin their history in the Eocene epoch, and, immediately following the Eocene, according to Scott, "marmots, squirrels, beavers, mice, pocket-gophers, and rabbits are already well established." The reference is to western America, but it may emphasize the antiquity of these groups of familiar creatures to remind the student that they were thus abundant before the Alps were formed.

Fig. 273.—Head of Dinotherium.

The order of Proboscidians is represented by elephantine creatures as far back as the Miocene. The Tertiary as well as the Quaternary elephants are widely distributed in both hemispheres. One of these is the Mastodon, so called from the form of its tooth (nipple tooth). Its remains occur in Tertiary strata of Texas, the

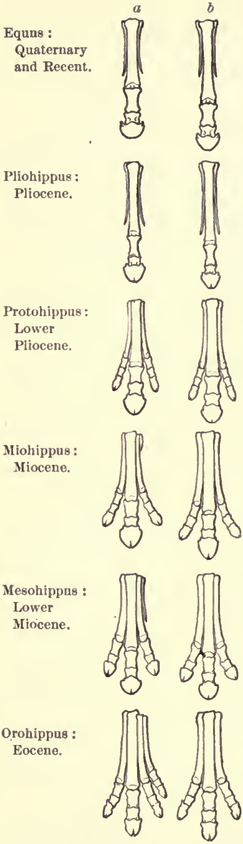


FIG. 274.—Development of fore foot (*a*) and hind foot (*b*) of the horse during Tertiary times.

Great Plains, England, France, Austria, India, and elsewhere. Other elephants differing from the Mastodon, chiefly in the labyrinthine patterns of their teeth, lived in the Tertiary period. The Dinotherium was a huge creature, somewhat like an elephant, whose remains have been found in many parts of Europe and in India. Its tusks extended downward, with a backward curve (Fig. 273). Of other familiar animals, the pig, or a swinelike creature, is found in the Wasatch Eocene beds. The earliest oxen were later, appearing in the Pliocene of the eastern continents. The camels are found in Tertiary times in both hemispheres, some going back as far as the Eocene.

The horses, tapirs, and rhinoceroses have had a long history and wide distribution, going back as far as the Eocene. Especially important and interesting is the ancestral history of the horse as worked out in detail by the late Professor Marsh, of Yale University, from fossils found in the Tertiary lake deposits of the West. Such a history affords most important support to the doctrine of evolution, and more and more of such evidence is supplied from year to year by the untiring labors of the paleontologists in the study of series of forms, both invertebrate and vertebrate. The earliest known horse is from Eocene deposits, and was about the size of a fox. It had three toes on its hind feet, and four and a rudimentary one on its fore feet. It is called Eohippus. The next stage is seen in Orohippus from the later Eocene, in which the rudimentary toe has disappeared. Mesohippus and Miohippus are Miocene horses, which are larger, and show the fourth toe in a rudimentary condition, as a splint, well up on the leg. In the Pliocene epoch came Protohippus and Pliohippus, with the side toes shortening up. Finally, in Equus, the post-Tertiary, and existing genus, the hoofs of the side toes have disappeared and are now mere splints.

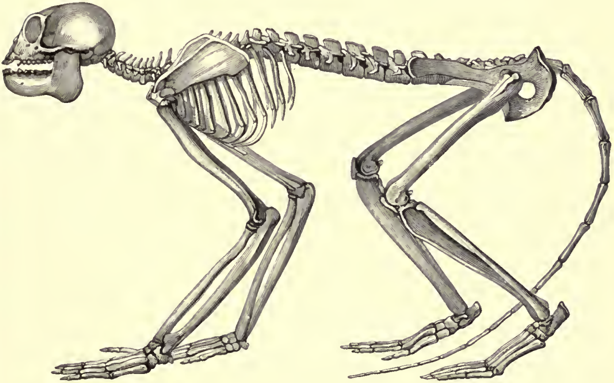

Fig. 275.—Mesopithecus, one of the earliest Tertiary monkeys.

Of the order of Primates, the monkeys go back far into the Eocene. In the time of the Wasatch, according to Scott, they were in great numbers and swarmed in the trees. They appear also in South American Tertiary, though most of the prominent orders of North American mammals were not known in the southern continent. Forms resembling the apes appear in the Miocene of Europe. No human remains, whether bones or implements, are of proved Tertiary age.

378. **Economic products of the Tertiary period.**—Soft coals, often in the form of lignite, occur in many places, in California and Oregon and in Europe, in northern Switzer-

Fig. 276.—Richmond earth under the microscope.

land, the Tyrol, Austria, and they are of special importance in northern Germany. The greensand of New Jersey is a valuable fertilizer, and likewise the phosphates of South Carolina and Florida. In Virginia the "Richmond earth" is a deposit, sometimes 30 feet thick, composed mainly of the siliceous shells of diatoms. The earth is used as an abrasive. A similar deposit in Bohemia was reported by Ehrenberg to contain many millions of shells in a cubic inch. Rock salt and gypsum occur in the Tertiary strata of Europe.

# CHAPTER XXV

## CENOZOIC ERA

### Quaternary or Pleistocene Period

379. This period extends from the close of the Tertiary until the present time. Tertiary time closes and Quaternary time begins with the coming on of the great glacial invasions; but as these came slowly, we have no narrow line of division. The name Quaternary, meaning *fourth*, is, like Tertiary, a convenient relic of usage. The term Pleistocene, often used, is similar to the names of the Tertiary epochs, and means móst recent.

The best subdivision of Quaternary time gives us two epochs, the Glacial and the Post-Glacial or Recent. This, again, is not a sharp division, for the time of final ice retreat was not the same for Illinois as for Labrador, and we may say that the Glacial epoch is still in progress in Greenland. Nor was the retreat necessarily contemporaneous on both sides of the Atlantic, though the history is believed to have been in fair correspondence in Europe and America.

### *The Glacial Epoch in North America*

380. **The drift.**—This is the name given to rocky materials and soils which have been removed from their sources, often to great distances. The transfer has frequently been made without regard to opposing slopes or the direction of existing valleys. The term is not used of materials carried along by rivers, except where the waters have come from melting glaciers. The most important element in the drift

Fig. 277.—Glacial till overlain by glacial flood gravel in southern Ohio. Height of section 30 feet.—After Wright.

is the bowlder clay, or till. The two terms mean the same, and refer to a clayey, sometimes loamy, mass of unstratified material, which is often filled with stones and small or large bowlders, inclosed in it without order. It often forms a part of terminal moraines, but chiefly it makes up the great ground moraine, or sheet, which covers the most of glaciated areas. It is composed in part of preglacial soils and stones loosened by weathering and pushed on by the glacier, and in part of rock flour and stones gathered from the bed rocks by the grinding and plucking of the glacier itself. These two kinds are mingled in various proportions.

The mechanically derived waste is often detected by its containing soluble minerals, such as lime, which would not be found in a soil produced mainly by weathering, or a residual soil, as it is called. This is the difference between the drift of such a State as New York and the soils of a State like Tennessee, over which no glacier has passed. The minerals of Tennessee soils are such as would be left from the local rocks after soluble matters have been swept away. The soils of southern New York, on the other hand, contain lime and other ingredients brought from central and northern New York and Canada.

The till is often blue in color and very tough and compact, having been pressed and rammed together by the weight and push of the glacier. Toward the surface it is often brownish or reddish, owing to post-glacial leaching and oxidation. The overlying till is sometimes looser in texture, having been less overridden or having been dropped by the ice in its final melting.

Another important element in the drift is its stratified materials. These are sands, gravels, and clays laid down by streams flowing from the glacier in glacial lakes or forming the kames and eskers already described (page 266). The study of erratic bowlders has given us much knowledge of the direction and character of the movements of the ice. Commonly the bowlder belongs to the till, but may be not infrequently found in the water-laid materials. The bowlders, as we have seen in the chapter on Glaciers, may be carried on the surface or plucked and shoved along by the under parts of the glacial stream. Some of great size have been reported. Several in New England have diameters of 20 to 60 feet and weigh thousands of tons.

FIG. 278.—Drift bowlder near Pittsfield, Mass.

In central New York are many masses of stratified rock, 10 to 20 feet across and often 10 feet thick, which have been carried 10 to 20 miles from known parent ledges. The distance of transport greatly varies, ranging from a few miles, as above, up to cases in which a transport of 500 miles has been proved. Thus bowlders are found in Ohio which have come from the pre-Paleozoic formations of Canada. The bowlders are always of smaller average size

Fig. 279.—Glacial bowlders washed from moraine, shore of Lake Erie. From report of the New York State Museum. Photograph by I. P. Bishop.

the farther one goes from the outcrops. This is due to wear and splitting in transit. They are not uncommonly carried to positions several hundred feet higher than the beds from which they came. Instances of an elevation of several thousand feet have been reported from some of the New England mountains. Wherever a bowlder can be traced to a definite source, it determines the direction of ice movement, at least for one stage or time.

381. **Striated rock surfaces.**—These accompany the drift and bear a close relation to it, as already explained. If on the whole the scratches radiate from a common ground, they point to a center of dispersion for the ice. They are widely distributed over northeastern America, and tell the story of the general movements of the ice sheet and of its local divergences, as around obstacles and along valleys, in front of the ice or under it. In general, the striæ over New England point southeastward, even disregarding the ridges of the Green Mountains. Over New York the general direction is southward, and farther to the west the common trend is to the southwest. Considering these as radial lines and tracing them back, they intersect in British America. The direction of the bowlder movements offers similar evidence, and leads us to sure conclusions as to the general course of the ice.

382. **Abandoned theories of the drift.**—During most of the first half of the century many of the above facts were seen, and honest but curious efforts made to explain them by theories of floods and icebergs. The confused stratification of glacial sands pointed, as was thought, to the tumult of such waters, and the southerly direction of carriage was held to prove that vast currents of water had come from the north. The scratches were explained as the work of icebergs grazing the bottom. President Hitchcock is an example of a powerful mind and keen observer grappling with the facts with the inadequate theories of his time. The weak points of the Diluvial

Theory were that it did not explain the unstratified drift, the continuity of the scratches, and, above all, that the source of the waters was purely imaginary.

383. **The glacial origin of the drift.**—This was proposed by Louis Agassiz, about 1840, from his study of glacial phe-

Fig. 280.—Recently glaciated cliff over the Aar glacier. The newly rubbed surface is about 60 feet high and shows in the lighter shade. The glacier ice in the foreground is free from morainic material and looks white, like snow, because of surface melting. Photograph by the author.

nomena in Switzerland. Far above the glaciers and far down the valleys are found striated rocks and morainic masses. Erratic blocks are common, and have even been carried across the great valley of Switzerland and left on the sides of the Jura Mountains. Gradually the theory was accepted in Great Britain and America, and it was recognized that wide fields of ice, far greater than those of Greenland at the present time, had covered the most of northern Europe and America. Thus the essential facts of the drift, of striated rock surfaces, and of the topography, are ex-

FIG. 281.—Glaciated spur in the Aar Valley. Photograph by the author.

plained. It is at the same time plain that water had much to do with shaping the drift along the lines of the ice front, in valleys, and in low grounds by the sea. Icebergs there were, and sometimes in abundance, but the great work was done by land ice.

384. **The centers of dispersion.**—In the light of present studies there seem to have been three important centers in

North America. The first of these, long recognized, lay between the St. Lawrence River and Hudson Bay, forming the highlands of Canada. Thence the ice extended over much of Canada and the northeastern United States (Laurentide Ice-sheet). Another gathering ground of ice is believed to have been on the low grounds about Hudson Bay westward, with movements far southward, over the plains of British America and the United States, and nearly to the base of the Canadian Rocky Mountains (Keewatin Ice-sheet). Another extensive glacial sheet occupied that mountain range, perhaps reaching over to the great sheet on the plains to the eastward, and sending out tongues to the Pacific on the west, as the Greenland glaciers now do into the surrounding seas. Farther south in the United States powerful local glaciers formed in the mountains both of the Continental Divide or Rocky Range and in the Sierra Nevada and its northern extensions in Oregon and Washington. The glaciers of Mount Rainier, Mount Shasta, and other peaks are shrunken remnants of the greater streams. In the Rocky Range they were found well south in Colorado. A glacier 60 miles long extended down the Animas River Valley in southwestern Colorado. Colorado Springs is now supplied with water from Lake Moraine, a small lake held in by a morainic dam halfway to the summit of Pike's Peak. The glaciers did not there come down to the plains. It should be observed that the ice flowed northward from the gathering grounds in British America, but failed to reach much of the territory bordering the arctic seas.

A word should be added as to the manner of dispersion. It is not to be supposed that all the ice which covered New York, for example, came from the Canadian highlands. No doubt much ice was formed by the Adirondack snows, a region which may thus be called a local center. The same is probably true of the New England mountains and other high grounds. That the great northern centers were important and dominated the whole territory is still evident from the course of the scratches and the distribution of the far-traveled erratics. How the warm climate of middle Tertiary became so changed is a question which is deferred to a later section in this chapter. No doubt snows fell widely over the broad areas affected, with many places of

FIG. 282.—Glaciated conglomerate, near Ouray, Col. Photograph by the author.

abundant precipitation, especially those mentioned in the north. It is not easy to think adequately of the long time which must have been required for the ice to creep over an area of some millions of square miles.

385. **The glacial boundary in the United States.**—In tracing this line the student should be reminded that the ice

did not occupy the whole of this outermost line of advance at one time. It seems to have melted far back from the western part of the line long before it left the eastern portion. All of New England was covered by ice, and the front was in the sea, or perhaps along the line of the southern islands, since belts of moraine cross Nantucket, Martha's Vineyard, Block Island, and Long Island. Professor Shaler has found a fan-shaped train of bowlders of a peculiar ore of iron leading south from northern Rhode Island, one erratic piece appearing on Martha's Vineyard. From Long Island and Staten Island the low morainic belt crosses central New Jersey. Thence it runs northwesterly into southwestern New York, where a small corner of that State remained free from the ice cover. Thence the student may follow its general direction on the map southwest to Cincinnati, curving across southern Indiana and Illinois westward, nearly along the line of Missouri River into Kansas. Thence the line stretched northwestward across Nebraska, South and North Dakota, and through Montana, where the territory of the northern Cordilleran glacial field is entered. The student must not suppose that this margin is all the way marked by a belt of moraines. Particularly along the broad stretches of the Mississippi Valley moraines are absent, and we have what Chamberlin has called an "attenuated pebbly border," showing drift but no topographic feature. This is quite natural. The ice front may have been temporary in that southern region, and accumulations then made were likely to be swept away and redistributed by the great discharge of waters from the melting ice which long sought that way to the sea.

386. **Thickness of the ice.**—This varied with the surface over which it moved. Thicknesses of a mile or more were probably common, with smaller measures toward the margin and perhaps much greater in the centers of accumulation. The Adirondack and White Mountains seem to have been covered. This accords with the above figure. The top of


IDEAL MAP
of
NORTH AMERICA
during the
ICE AGE
T.C.Chamberlin
1894,

FIG. 283.

Mount Katahdin is thought to have been a nunatak, or island rising through the ice. The flow of a sheet relatively so thin, for long distances over rough ground seems surprising. But an inclination of the ice surface of 40 feet per mile is sufficient for flow in Greenland to-day, and we must also remember that this portion of the continent was much higher than now—how much is not well known.

387. **Subdivisions of the Glacial epoch.**—Final statements can not be made, but students of glacial phenomena in the great Mississippi region are agreed that there were several important advances and retreats of the ice. The limits of the more important advances are well known, but the distances to which the ice retired to the north in these warm inter-glacial intervals are not so well determined. That the retreats were much more than fluctuations of the margin is believed for several reasons. Beds of vegetable soil, with plant remains, are found between younger and older sheets of till. These remains indicate a warmer climate than would be found close to an ice sheet. The outer and older sheets of till are much more weathered and denuded than the younger, thus proving difference in time. The inter-glacial intervals were times of submergence or low-lying lands, as well as of warmer temperatures. Among the more important sub-epochs or periods of advance, we note the Kansan, marking the farthest extension of the ice into eastern Kansas; the Iowan, marked by a sheet of till reaching into northeastern Iowa; and the Wisconsin, marked by a splendid series of deposits in that State. The last were first studied by Chamberlin, and named by him the Kettle Moraine. Other and intermediate stages have also been made out. The Wisconsin stage is thought to be contemporary with the farthest extension of ice in Pennsylvania and eastward. Thus, if there were retreats and advances as extensive in the East as in the West, the deposits were overridden and the evidence obscured. Dana thinks that greater supplies of snow in the East kept up the flow, and pushed the glacial

limit ever well to the southward. But some evidence for the diversity of the Glacial epoch in the East has been found.

388. **Advance of the ice as affected by topography.**—An advancing sheet would flow about an opposing hill or mountain, and if the supply was great enough would overtop it and cover it from sight. Valleys lying more or less in the direction of flow, would be entered first by tongues projecting forward perhaps a number of miles from the main body. Great valleys, such as are occupied by the Great Lakes, were filled by vast ice lobes. Such lobes occupied the basin of Lake Superior, Lake Michigan, Lake Erie, and others. Gradually the ice covered the intervening higher grounds and moved out upon the central Mississippi Valley.

389. **Recession of the ice.**—Why the climate changed is a question for later consideration. We are concerned now only with the fact and its consequences. The sheet did not melt away at a uniform rate, but with long pauses from time to time, in which moraines were accumulated. Even in these pauses the front was not stationary, but fluctuated like those of the Swiss glaciers. Hence the moraines are not single ridges, but belts of rough ground. Many belts of moraine may be traced in Minnesota, Iowa, and westward. Especially do we see them as successive belts, south of the lakes in Illinois, Indiana, Ohio, and Michigan, marking the shrinking of the great ice sheet. Such belts form the terminal moraine south of New England, and are seen across New York and Massachusetts and elsewhere.

390. **Floods from the melting ice sheet.**—The ice in its fullest extension lay far over in the basins of the Susquehanna, Ohio, and Mississippi Rivers. As melting proceeded, these great rivers, by means of their branches, gathered the drainage and carried the waters to the sea. The coarser waste, and in times of low altitude of the lands, fine clays as well,

Fig. 284.—Glacial flood gravels, North Albany, N. Y. Photograph by the New York State Museum.

were strewn along the valleys. These are now found as valley trains of aqueo-glacial *débris*, filling the valleys of the Northern States, often to depths of several hundred feet. At intervals in these valleys kames are often found, which are moraines, formed during a pause in the recession. In front of them overwash aprons or deltalike terraces often appear, and glacial lakes and swamps are common. The valleys of the central New York plateau offer many examples.

391. **Glacial lakes, north of the Mississippi-Hudson Bay and Mississippi-St. Lawrence watersheds.**—As the ice front began to lie to the north of these watersheds, lakes formed between their height of land and the ice lying to the north of it. Their outlets passed through the lowest notches in the divide, and carried the waters to the Gulf of Mexico and the Chesapeake Bay. One of these old outlets is seen in Brown's Valley in western Minnesota, where a typical stream bed crosses the watershed, but is now dry, save for two shallow lakes. The lake that formed to the northward gradually became longer as the ice melted back, until it extended over 700 miles through western Minnesota, eastern Dakota, and far into Manitoba, covering the area of the present Winnipeg Lake. This lake is called Lake Agassiz, in honor of the author of the Glacial Theory. The successive beaches of this lake have been traced for hundreds of miles on the east and west sides of the area. Most geologists believe that the retreating ice front was the barrier which held it on the north. An elaborate report on Lake Agassiz, by Mr. Warren Upham, is published by the United States Geological Survey. The muds deposited in it form great areas of valuable wheat lands. Similarly lakes were formed in the region of the head of Lakes Superior, Michigan, and Erie, as the ice gave way. One great avenue of discharge was near the site of Chicago, by the valley of the Illinois River to the Mississippi. Another was across the watershed of Fort Wayne, Ind. Yet another was through the valley of Sene-

ca Lake over the site of Horseheads and Elmira, N. Y. As the ice receded and the lakes grew, they merged into one another at lower and lower levels, forming vast sheets of water. One of these is called Lake Warren. Its beaches now lie about 870 feet above sea level, and have been traced

Fig. 285.—Scratched stone from the bowlder clay of central New York.

from western New York far westward. The outlet was to the west, across the site of Chicago and along the line of the Drainage Canal. These lakes, as most believe, were held by glacial dams on the north and east.

The time came when the ice began to melt out of the Mohawk Valley in eastern New York, and thus to offer a lower path to the sea than could be had by the Horseheads, Fort Wayne, or even by the Chicago region. Most remarkable abandoned channels of these eastward streams cross the high ridges of land, a few miles south of Syracuse,

N. Y. Rocky beds, terraces, deltas, and cliffs, whose waterfalls rivaled Niagara, are there seen in wonderful perfection. The present divide between the Mohawk and Lake Ontario basins at Rome, N. Y., is 445 feet above the sea. When this depression was clear, all the drainage of the Great Lakes sought the Atlantic by way of the Mohawk and Hudson Valleys. When the vast expanse of waters was thus drawn down, the Niagara escarpment was uncovered in western New York and Ontario. Lake Erie was separated from its northern neighbor, the drainage of Erie and the upper lakes found its way across the plateau north of Buffalo to the edge of the escarpment, and the Niagara Falls began. Niagara is a mammoth example of what happened in a multitude of instances on the retirement of the ice. The waters, not able to find their original lower channel, gained a higher outlet across the plateau. This plateau being bounded on the north by a cliff, a great waterfall came into being. Niagara, with its gorge and rapids, has an elaborate history which can not be given here. Interested students should consult the writings of Gilbert, Taylor, Spencer, and others.

The greater ancestor of Lake Ontario, which then had its outlet at Rome, is called Lake Iroquois, from the early Indian confederacy of New York. Its ancient beaches extend through western New York to the opening of the Mohawk Valley and northward to Watertown. At length the glacier melted out of the St. Lawrence Valley, the Rome outlet was abandoned, and the present drainage established. The reality of these ancient bodies of water is vividly proved by the elevated beaches which are conspicuous about all the Great Lakes. Around Lake Superior they are found at intervals to a height of more than 500 feet above the lake. In Ohio and Michigan they run about the lake, roughly parallel to the present shores. Others are seen about Lakes Michigan and Huron. They are not now horizontal, having been carried up on the northeast by warping of the continent. Thus the old beach of Lake Iroquois is 116 feet above Lake Ontario, at the west end, but 485 feet above at Watertown on the northeast.

392. **Lake Bonneville.**—A great body of water of which Great Salt Lake is the shrunken representative, formerly occupied much of Utah in the eastern part of the great basin. It is called Bonneville, after the explorer, Captain Bonneville, who visited the region about 1833. The existence of a larger lake is proved by a series of very perfect beaches, on the adjacent mountain slopes. A brief account of this lake is found on page 279. Reference is here again made to it, because it probably belongs to the Glacial epoch, when precipitation was much greater in that region, and great glaciers occupied the valleys of the Wasatch Mountains on the east. A similar lake, smaller and of less compact form, occupied the low grounds of Nevada, and is known as Lake Lahontan.

393. **The Champlain depression.**—Reference has already been made to the inter-glacial intervals characterized by low-lying lands, warm climate, and sluggish stream action. These are most clearly shown by the succession of deposits in the West.

It is also known that a great sinking of the lands took place during the waning of the ice sheet, and after its departure in the East. This stage has long been called Champlain, from marine deposits on the borders of Lake Champlain. The depression was enough to allow the sea to extend over Manhattan Island, up the Hudson Valley. Marine waters in the Champlain Valley merged with a great St. Lawrence Gulf and extended into Lake Ontario. The records of the subsidence are found first in a series of terraces, extending along the Hudson and Champlain Valleys. They consist of sands, gravels, and clays, and are conspicuous features of the landscape. At the mouths of side valleys, like the Fishkill, Catskill, Mohawk, and Hoosick, they take the form of deltas. These terraces mark a submergence of 70 feet at New York, 180 feet about Newburg, over 300 feet at Albany, and from 400 to 500 feet on Lake Champlain. In the Champlain terrace of the Vermont side the remains of a whale were found. The terraces are still higher on the St. Lawrence. Raised beaches show a submergence of 200 to 300 feet on the coast of Maine. Stratified glacial deposits more than 4,000 feet thick are found on the coast of Alaska, indicating subsidence and later uplift to that amount in that region. This may perhaps have been contemporary with the subsidence in the East.

394. **River drainage re-established.**—As the ice retreated, the surface waters resumed their work with somewhat changed conditions. The preglacial valleys had been very generally graded up with waste, either coarse materials deposited by swift streams from the glacier, or clays deposited by sluggish streams and in lakes, during times of depression. These buried or half-filled valleys are known chiefly through borings made for oil, gas, water, or other products. All the streams entering Lake Erie from the south flow far above the ancient valley bottoms. From 200 to more than 300 feet of fine clays lie in some valleys of central New York.

In many cases a valley, or a section of it, was blockaded by morainic waste, and the streams were unable there to maintain their ancient courses. As a result, lakes were formed above the barrier, and a gorge cut past the blockade at a greater or less distance from it, until the lake was drained. Illustrations of such changes have already been given. Sometimes a buried channel is tapped with disastrous results in mining. In 1885 the roof of a coal mine near Nanticoke, Pa., caved in, and a flood of glacial gravel entrapped a number of miners.

In some cases important diversions or reversals of drainage occurred. The head waters of the Alleghany are very close to Lake Erie, but borings have proved that the rock floors of valleys of northwestern Pennsylvania descend toward Lake Erie. Glacial materials have graded them up and turned the surface slope to the south. In a similar

Fig. 286.—Iroquois shore near Pierrepont Manor, N. Y. Terrace cut from till, and set with bowlders derived from it. G. S. A. Photographs No. 128. Photograph by G. K. Gilbert.

manner the head waters of the Mohawk were diverted from their preglacial connection with the St. Lawrence system.

395. **Topographic products of glaciation.**—Some of these have already been noticed. Such are kettle-hole lake basins, Morainic-barrier basins, kames, drumlins, and eskers. In eastern Massachusetts and elsewhere occur sand plains, or fossil deltas, made in temporary bodies of water at the ice front, and since exposed and sometimes dissected. Great plains of washed gravel and sand stretch away from ancient ice limits, where the ice deployed on level grounds,

while in a hilly region the washed material forms trains in the valleys. In cases of sufficient uplift and vigorous flow of water since the time of valley filling, the valley trains may be partly cut away and a system of terraces formed. While low grounds were in many cases graded up, it is also true that higher and exposed grounds and isolated rock masses suffered abrasion and often considerable degradation. Facts are not available to show how much the tops of mountains and hills have suffered in this way; but we know that ordinary subaërial denudation produces narrow hilltops and sharp spurs in a region of considerable topographical relief. We can not doubt that many such areas existed before the ice invasion, where now we find subdued forms, rounded summits, and low drumlinoid hills. The general tendency has been, therefore, to fill up depressions, pare down elevations, and reduce the surface to uniformity. On the other hand, such topography is relieved by morainic hills and by post-glacial gorges, and it is possible that natural scenery as a whole is more varied because of the great invasion.

396. **The driftless area of the upper Mississippi Valley.**—The above-named principles find illustration in a large tract lying mainly in Wisconsin, over which glacial ice did not move. It has an area of about 10,000 square miles, and extends from central Wisconsin, a little past the south and west boundaries, into Illinois and Iowa. It has great value as a standard of comparison with glaciated areas, lying in the same latitude and having similar rock formations. On the north and east the area is bordered by heavy moraines, marking the bounds of the Lake Superior and Lake Michigan ice lobes. There are no moraines on the south and west borders. The soils are residual—that is, formed from the underlying rocks, and poor in the soluble elements, such as lime. The transition, as in the southern unglaciated regions, is gradual, from the soil, to decayed and then to the unmodified bed rock. The average thickness of the

soils, taking 1,800 trials into account, is about 7 feet. There is no erratic material except that brought in from the glaciated border, along the valleys.

The topography differs much from that of the surrounding territory. There are no waterfalls, while they are common on the borders. The valleys are wide, with flowing slopes or with recession cliffs, but there are no narrow gorges. There are frail remnant pillars of rock within the region, but none outside. The drainage system is perfected, and there are no lakes. Valley trains, with drift material, cross

Fig. 287.—Glacial flutings of bed rock, near Burlington, Ia.

the tract, as along the Wisconsin River, which comes in from the glaciated area on the northeast. The cause of such a gap in the glaciated territory is not well understood. One suggested reason is the control of the great ice currents by the Lake Superior and Lake Michigan valleys, carrying the ice on either side of the higher grounds of northern Wisconsin.* Interested students may find a full account in a

* A later theory is that the Laurentide glacier failed to reach the region from the east, while the Keewatin glacier fell short of it on the west.

paper by Chamberlin and Salisbury in the Sixth Annual Report of the United States Geological Survey.

397. **The Glacial epoch in other lands.**—The facts about the ice invasion in Europe are well known. From the mountains of Scandinavia the ice appears to have moved in every direction, though the limits are naturally less known on the north than elsewhere. Great Britain and Ireland were nearly covered, the ice coming down almost to the line of the Thames. As in America, the Glacial epoch was largely a time of elevation. The bottoms of the shallow North Sea were land, and occupied by ice, which brought Scandinavian bowlders to the eastern parts of England. On the Continent the southern limit of the ice was near Dresden and Brussels, and considerably north of Moscow. Thus the low grounds of North Germany were covered, and the entire Baltic area. There were several invasions and recessions, and there were glaciers in the mountains of Wales and of the English lake district, and among the Highlands of Scotland, long after the ice melted off from the lowlands of Great Britain. Scandinavia remained long a region of great ice fields, and the glaciers of Norway are the surviving remnant of her early ice sheets. The plains of Russia were covered far to the east, but Siberia, like Alaska, seems largely to have escaped.

Reference has been made to glacial extension in the Alps. The range was mantled with ice and snow, and sent its glaciers out upon the plains of Bavaria about Munich, westward upon the flanks of the Jura, and as far as Lyons in the Rhone Valley and southward upon the plains of Italy, where now vast moraines, in some cases 1,500 feet high, testify to the magnitude of the glaciers that occupied the southern valleys of the Alps. Similarly, there was great extension of the glaciers of the Pyrenees, Carpathians, Caucasus, and Himalayas. The same is true of the high Andes and of the southern extremity of South America, also of the mountains of New Zealand and Australia. Much remains to be known of these remote areas of former glaciation in Asia and the Pacific, as well as of the present condition and extension of the antarctic ice fields.

398. **Causes of glacial climate.**—Much has been written on this subject, but definite additions to our knowledge are as yet small. Both astronomical and geographical changes have been thought to be instrumental, and it may be that the true cause lies in the union of both. Some astronomical theories may be dismissed. Such are the following: That glacial climate is due to variations of the sun's heat from time to time; that there are great variations in the temperature of the spaces traversed by the solar system; that the position of the poles has materially shifted; and that glaciation is due to the cooling of the planet.

Croll's theory, as it is called, still requires attention and is held by many, or is at least believed to contain a part of the truth. For a full account of it the student must consult the larger text-books or special works. The theory rests, in brief, upon changes in the eccentricity or the elongation of the earth's orbit around the sun, and upon the precession of the equinoxes. We now have summer when the earth is farthest from the sun, because the northern hemisphere is inclined to the sun in that part of the earth's orbit. But it results from the precession of the equinoxes that 10,500 years ago there was summer in the northern hemisphere, when the earth was nearest the sun, and winter while the earth was passing through the remoter and longer part of its orbit—that is, the summer was short and hot and the winter long and cold. Let this fact be first understood. Now consider that at somewhat irregular intervals of tens or even hundreds of thousands of years the earth's orbit is greatly stretched out, so that the earth is 14,000,000 miles nearer the sun in one part of the year than at another. When winter occurs at the greater distance, it will be very long and very cold, and the summer very short. Thus it is thought that the northern and southern hemispheres would tend toward glacial conditions as they alternately came to these severe winters. The author of the theory urges other considerations which can not be included here. The evidence for glacial and inter-glacial epochs indicates periodicity in glaciation, and this is favorable to an astronomical cause. So too are the successive moraines of recession, indicating periodical pauses in the melting off of an ice sheet. But, on the other hand, we know of but one great glaciation in the earth's history, and on the astronomical theory the ice age should have been several times repeated. The undoubted evidence of glaciation at the close of Paleozoic time in India and Australia does not essentially modify this objection. Nor have we evidence of an alternation of invasions in the north and south hemispheres, as the theory seems to require.

For these and other reasons many geologists hold to geographical causes. Such possible causes are redistribution of land and water, changes in the direction of the ocean currents, and especially great increase in the height of the lands. We have already seen how widely the temperate latitudes of eastern America and western Europe differ through the effects of the Gulf Stream upon the latter ; and we know how rapidly the conditions of climate change as we go from low to high grounds. In comparatively late geological times the ocean waters covered the present Isthmus of Panama, and apparently swept across the Mediterranean region and southern Asia in free course around the world. Late geological time has seen Great Britain joined to the continent by elevation, and diminished to a group of small islands by submergence.

Now we have repeated occasion to observe that North America and Europe, especially toward the north, were areas of great elevation in the closing stages of the Tertiary and far into the Glacial epoch of the Quaternary period.* The most impressive proof of this is in the fiords or drowned valleys of both American coasts, and of Scotland, Norway, and other parts of northern Europe. This great elevation is believed by many to be the chief cause of the glacial refrigeration of climate. If most of the precipitated moisture came down as snow rather than rain, with short summers for melting, the reign of the ice would begin. Once started, glacial conditions tend to perpetuate themselves by chilling the atmosphere and condensing the vapors of the melting season into a mantle of clouds.

399. **Duration and date of the Glacial epoch.**—The succession of ice invasions proves impressively the great length of the epoch. Historical measures of time are small as compared with those needed for the ice to advance from the heart of British America to the Missouri River, and melt off again. And even advocates of the essential unity of the glacial invasion admit the immense time required for fluctuations along the margin of the ice, and for the successive deposits of the many moraines of recession.

No satisfactory computations as to the lapse of time since the ice departed have been made. The last period of great eccentricity of the earth's orbit was about 70,000 years ago. Those who accept Croll's theory would therefore be disposed to ascribe such an antiquity to the invasion. But many hold the post-Glacial epoch to be much shorter. As has been stated, it is known that the present Niagara began its work after the ice had left the Mohawk Valley. Computations based on the present rate of gorge-cutting, or recession of the falls, have led to view that the 7 miles of the gorge have been made in 7,000 to 8,000 years. In harmony with this, similar results are given from the recession of the Falls of St. Anthony, at Minneapolis. And

* Reference should here be made to the elaborate argument of Suess (French edition La Face de la Terre) that such changes are due to oscillations of the sea rather than of the land.

it is claimed that many topographic forms built of loose sands and gravels could not have kept their contours for more than a few thousand years of exposure. But, on the other hand, there are strong reasons for thinking that the erosion of the Niagara gorge has not been uniform, and that the time is vastly greater. It should also be remembered that the perishable hills to which reference has been made were commonly protected by forests until recent centuries, at least in America. The date of the Glacial epoch must therefore be regarded as uncertain, but there is much to encourage the belief that our knowledge will become more definite.

400. **General advantages of glaciation.**—In all the great lakes which were caused by the melting of the ice and the retention of the waters fine offshore muds were spread over wide areas. These form valuable soils, and are found in Minnesota, Dakota, and Manitoba, along the bottoms of Lake Agassiz, and also bordering the Great Lakes on all the lower grounds, as about Lake Erie in Ontario and Ohio, and south of Lake Erie and Lake Ontario in New York. The valley of Utah also is floored in the same manner, and shows the greatest fertility under irrigation.

Professor Shaler has called attention to the renewal of all soils that were subjected to the glacial plow and received accessions of coarser mechanically derived materials. These, he affirms, will long continue to yield to plants the elements of nutrition by constant disintegration, while residual soils will become poor, after their quota of vegetable matter is exhausted. The sum total of water power of the Northern States has been vastly increased, because most streams have by glaciation been set to flow at higher levels. Rapids and waterfalls are common on many streams which before the ice invasion moved sluggishly along near base level. The increased variety of natural scenery has already received mention, and reference has been made to the gorges and waterfalls as chiefly of glacial origin. The same principle receives perhaps its fullest illustration in the thousands of beautiful lakes which serve as places of resort, afford healthful recreation in many forms, and more and more furnish to the cities and towns supplies of pure water.

### Life in the Quaternary Epoch

401. **Migrations caused by ice invasions.**—These took place extensively not only because the ice actually occupied the ancient habitat of many groups, but because it chilled the climate of adjacent regions. Forests of particular species were crushed or were dying off on one side and slowly advancing on the other. Or they might be destroyed altogether if the advance was too rapid and the climatic strain on the vitality of the species was too great. In many cases such forced migrations would modify the species, and change the proportions of the various kinds which made up a fauna or a flora. When the ice retreated the groups would in some measure push back and recover their territory. Some arctic forms did not go back, but found congenial homes on the mountain tops. Plants and insects thus gained a place among the Alps, or even the summits of the White Mountains or the Adirondacks, where they are found to-day, far separated from their kind. Other heights, outside of the glacial territory, do not possess these arctic forms.

### Mammalian Life in the Quaternary Period

402. The Tertiary marine invertebrates are more and more like those of the present, and the same is therefore true of Quaternary times. These forms therefore need not concern us here. But the mammalian species of the early Quaternary are distinct from those of the Tertiary and are in their turn extinct. Some were of great size, and wandered over continents where none of their modern relations are found. With them man himself appeared on the scene,

at the summit of the series of living forms, and about to become the master of the organic and the inorganic world.

The most conspicuous Quaternary creatures of North America were the elephants. They were much larger and heavier than

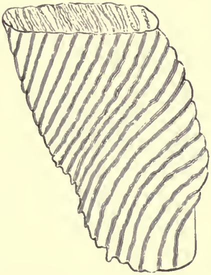

FIG. 288.—Tooth of Quaternary elephant (⅛ natural size).

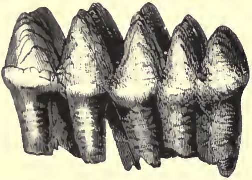

FIG. 289.—Tooth of mastodon.

modern elephants, and ranged over the entire United States and parts of Canada and Alaska. The mastodons also came over from the Tertiary (with new species, how-

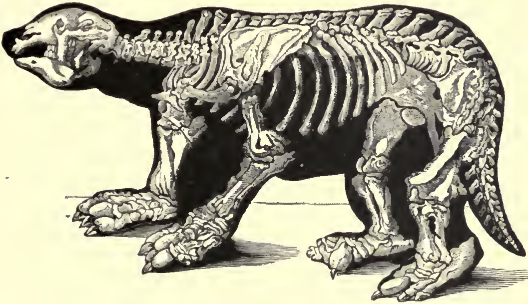

FIG. 290.—Megatherium.

ever), and have also a wide distribution. They have been sometimes preserved by miring in soft grounds, and there have been found in connection with their skeletons masses of grass and herbs which the creature had devoured, but had not digested. The skeleton of an American mastodon now in the British Museum measures 17 feet in length and 11 feet in height. There were also stags and buffaloes of great size, and many horses. A few remains of the saber-

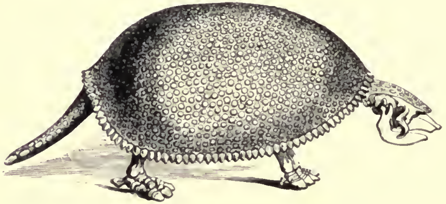

Fig. 291.—Extinct armadillo, Glyptodon.

toothed tiger and the bear have been found in the South and West, but the most of North American mammals lived on vegetation.

In South America a large Quaternary fauna has passed away. The dominant forms are known as edentates, some of them gigantic creatures, but in form like sloths and armadillos. One species is Megatherium (great beast), sometimes nearly 20 feet long, with massive body and thick, clumsy legs and tail. Other edentates (Glyptodon) had an immense shelly armor, much resembling the carapace of a turtle.

The European mammals are of great number and often also of large size. They include many forms now confined to warmer climates, and, on the other hand, animals like the reindeer occur far south, bearing unmistakable witness to great alternations of climate. European mammalian bones have been abundantly found in the deposits of rivers and in caverns. The latter were often the haunts of wild animals, as the hyenas, and their bones with those of their prey are found together. The Irish elk is sometimes found in great and perfect skeletons in peat bogs in which the creature had sunk. One specimen has a spread of antlers of 12 feet. A single cavern in England afforded bones of hyena, elephant, rhinoceros, hippopotamus, cave

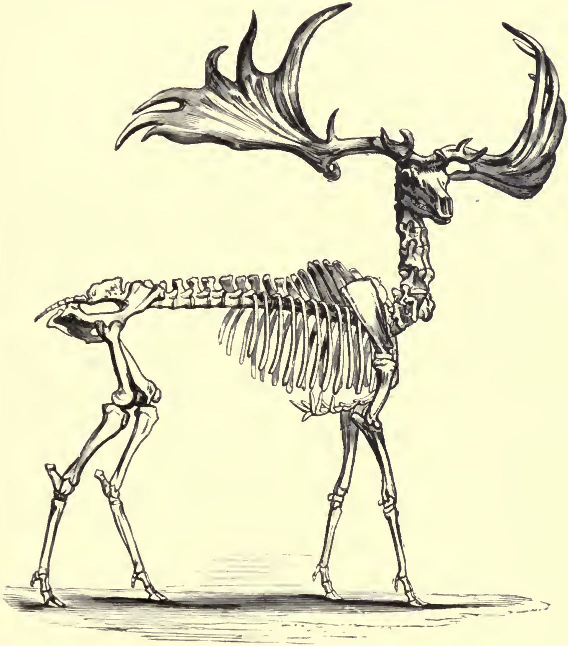

FIG. 292.—Skeleton of the Irish elk.

lion, brown bear, and many other species. The elephant or mammoth, as we have seen, was almost everywhere in North America, and ranged through northern Europe and northern Asia, indicating a common highway of migration across the Bering Straits region in the time of continental elevation. Perfect specimens with flesh and covering of wool and long hair have been found frozen into the ice of the Lena River. The dogs ate the flesh of this creature of an extinct species, and the tusks have been sought for export, and thus have made their contribution to the trade in ivory. The length of one of these Siberian mammoths was 16½ feet and the height 9½ feet. The distribution of mammals in Europe proves land connection and freedom of migration between England and the Continent, and between southern Europe and Africa. The reindeer at one time grazed southward as far as the Alps and the Pyrenees. The existence, however, of lions, elephants, hippopotami, and other forms far north in Europe and Asia, indicates a warmer climate than the present as having prevailed. Even the warm-clad mammoth could not now live in the far north of Siberia.

403. **Man.**—Much remains to be learned of the advent of man upon the planet. The broad facts of our present knowledge are that the human race has great antiquity in comparison with the historical period, and that the primitive man lived as a rude savage, and was a contemporary of several species of mammals which are now extinct. Our knowledge of man's antiquity depends upon several branches of science, particularly upon history, philology, anthropology, archæology, and geology. History carries us to the earliest extant records, as of Egypt. Philology and anthropology require high antiquity for the development of languages and races, for, whatever views are taken of man's origin, it is agreed that he began as one type in a single locality. Archæology finds its records in objects made or used by man, and draws a picture of his life. Geology, with paleontology, refers the ancient man to his place in the chain of life, amid the succession of physical events. The antiquity of the primitive man must, therefore, be determined mainly by our science.

It has been agreed to call the earliest man Paleolithic (ancient stone), because he used the rudest and roughest forms of stone implements. They were chipped, but never

FIG. 293.—Paleolithic drawing of a mammoth on a surface of horn.

polished. Here the reference is chiefly to Europe, because in America the age of chipped stone continued until the retirement of the Indians before the early settlers. Paleo-

FIG. 294.—(Supposed) Paleolith found in New Jersey. Shows the general character of Paleolithic flints.

lithic man lived often in caverns and subsisted upon berries and such fishes and land animals as he could contrive to catch. His implements, and rarely his bones, are found in some caverns of England, France, Belgium, and elsewhere in Europe, in association with the bones of elephants, lions, bears, hyenas, and other extinct animals. Many flint implements have been found in the terraces of rivers, as in northern France. The situation is such as to prove deposit closely following an ice invasion. The more ancient of the relics of man in Europe are believed to date from an interglacial epoch, for these are earlier than the reindeer man of southern France who belongs to the later great glaciation of central Europe. These later Paleolithic remains (sometimes called Mesolithic) are more advanced, and include quite skilled drawings of the mammoth on pieces of ivory. No undisputed Paleolithic remains, associated with glacial deposits, have been found in America. Chipped implements found at Trenton, N. J., and in the drift of Ohio and Indiana, have been held to be true Paleoliths, or representatives of the earliest man, but the evidence is deemed insufficient by many.

It is agreed by the highest authorities that the skulls of Paleolithic men thus far found are truly human, and are not intermediate between man and any lower form. Students of geology should know, however, that if a "missing link" were found, it would not be a creature between man and an ape, but between man and some ancestral type of long ago. In this, as in all questions, the truth should be sought without prejudice or fear. The antiquity of man and his possible evolution from lower forms of life are questions of science. No answer which science may render is inconsistent with the highest views of our origin and destiny.

Some relics have been supposed to indicate a Tertiary man, but the general verdict on this subject is "not proved." It could hardly be useful to state figures in relation to the age of the race. They would be only conjectural, and it is better to wait for more knowledge. If the time of the Glacial epoch, and of its various subdivisions, becomes better known, real light may be thrown upon the other question, which, as we now see, is closely related to it.

Following Paleolithic is the Neolithic man. He used implements of polished stone and of bone, often very skillfully and perfectly made. Many of the animals found with Paleolithic remains had now become extinct, and some animals, such as goats, oxen, sheep, and dogs, were domesticated. Cereals were also cultivated. The Kitchen Middens or primitive shell heaps of the Baltic shores, and the Lake Dwellings of Switzerland, belong to the Neolithic times. Then followed the Bronze and Iron ages, as they were called. These were not contemporaneous in different regions, and, like the Neolithic, belong more to archæology and less to geology than is the case with the evidence for Paleolithic man.

It should be remarked that since man attained any numbers, he has been a powerful agent for the redistribution and even for the extinction of many groups of animals and plants, as well as for actual modifications of the earth's surface.

404. **Geological time.**—Our study would have been to little purpose if it were now needful to urge that the history of the earth is long. But a brief notice of the opinions of geologists on this subject will be suitable at this point. We may observe that physicists and astronomers are inclined to shorten the estimates of geological time on the basis of the rate of cooling and other considerations, and to place a limit of ten or twenty million years for the interval from the first nebula to the present. Geologists would all consider this too short in the light of physical changes and of a great number of organic revolutions. The making and unmaking of hundreds of rock formations, and the inscription upon the face of the continents of many successive topographies, are the constant material of geological study. The student will perhaps gain the most real and serviceable appreciation of the enormous duration of

terrestrial history if he will think of many single phases, each one of which demands long duration. He may take, for example, any one of the Paleozoic limestones, the making of a single thick bed of coal, the accumulation of the English chalk, the subduing of the Appalachian mountains to the Cretaceous peneplain, the several glacial and inter-glacial phases of the Glacial epoch, the formation of great coral reefs, or the making of large modern deltas. And behind all this is the expanse of pre-Paleozoic time, believed by Dana to be longer than all time from the opening Paleozoic until to-day. Such considerations influence one's thought much more than figures can do. But even figures based on rational estimates are not without value. On the basis of the average rate of denudation and sedimentation, Upham arrives at 28,000,000 years for all time from the beginning of the Paleozoic era. There are many possibilities of error in such an estimate. The rapidity of denudation depends on climate, the height of the lands, the acids of the atmosphere, and perhaps other factors. The lack of a covering of plants may have made the destruction of the lands in early periods much more swift than in later time. Dana estimates Paleozoic, Mesozoic, and Cenozoic time in the ratio of 12 : 3 : 1. Reckoning 36,000,000 years for Paleozoic time, he finds 36,000,000 + 9,000,000 + 3,000,000 = 48,000,000 years, which he holds to be less than half the period of the earth's whole development. Dr. James Croll estimates 72,000,000 years for the sedimentary rocks; Wallace, on the other hand, assumes 28,000,000 years for the same. This diversity does not mean that our knowledge is of no value, for all these magnitudes are of the same order, and the lowest are as far beyond our imagination as the highest. Vast duration is the verdict of all who know the facts that must be reckoned with. Not many students of the earth could be found who would not accept Walcott's statement that the history is to be reckoned by tens, not by hundreds, of millions of years.

To gain in any measure this conception of the immensity of time is one of the highest rewards of study.

405. **Orderly progress of the earth's history.**—Progressive unfolding has been the law throughout. We began our study of Part III with the affirmation of two great lines of evolution, the geographical and the organic. The continents began with straggling and isolated lands, and grew and consolidated by successive deposit and uplift. Depressions have intervened, but the goal has not been obscured. Progress has usually been quiet, but not infrequently energy has gathered, until vast and almost catastrophic changes followed in quick succession. Amid every diversity of slow and swift, uplift and down wear, all forces have wrought together to make lands of moderate average altitude, great areas with genial climate, rocks covered with soil, and soil supporting abundant life.

Equally wonderful in its majestic ongoing has been the progress of life. From the earliest fossil-bearing rocks to the last sands laid on the beach the tendency of life has on the whole been upward. Lowly forms have given way to higher, and clumsy generalized types like the early fishes, reptiles, and birds, have yielded the stage to nobler and more special groups. The land forms came last, but steadily gained in numbers, variety, and physical rank, until signs of intelligence appeared, and these received their crown in man.

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